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INDUSTRY REVIEW OF A CREW-CENTERED COCKPIT DESIGN PROCESS AND TOOLSET

Edward Lehman
Michael Rountree
Katherine Jackson

VEDA INCORPORATED
5200 SPRINGFIELD PIKE, SUITE 200
DAYTON, OH 45431-1265

Brett Storey

STOREY CONSULTING
2728 FIELD COURT
ROCKLIN, CA 95765-4913

Philip Kulwicki
Julie Cohen

CREW SYSTEMS DIRECTORATE
HUMAN ENGINEERING DIVISION
WRIGHT-PATTERSON AFB, OH 45433-7022

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FOR THE COMMANDER

Kenneth R Boff

KENNETH R. BOFF, Chief
Human Engineering Division
Armstrong Laboratory

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Lehman, E., Rountree, M., Jackson, K.(Ed.), Storey, B., Kulwicki, P., Cohen, J.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Veda Incorporated
5200 Springfield Pike
Suite 200
Dayton, OH 45431-1265

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13. ABSTRACT *(Maximum 200 words)*

This report contains the results of an industry review done for the Crew-Centered Cockpit Design (CCCD) Field Demonstration Program, USAF Contract F33615-92-C-5936. The objectives of the program are to upgrade and validate a new system for cockpit design. The system consists of a Crew-Centered System Design Process (CSDP) and a Cockpit Design System (CDS). The CSDP is intended to improve design practice, allowing designers to base decisions on mission requirements and crew capabilities while meeting installation constraints. The CDS offers improved design efficiency and includes traceability functions that preserve the rationale for design decisions.

The CCCD Program Office recognizes that the acceptance and long-term utility of the CCCD products depend on the interest and support of the cockpit development community, which includes aircraft prime contractors and government aircraft acquisition organizations. For this reason, a survey of four aircraft prime contractors was made during August and September of 1993. The objective of the survey was to elicit end-user requirements for CCCD products. Information was obtained from engineers, scientists, and managers who were involved in different crew station activities including pilot-vehicle interface (PVI) design, crew station design, human factors analysis, systems engineering, and operational analysis. This report documents the results of the survey.

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PREFACE

This report was prepared at Veda Incorporated in Dayton, Ohio. The work was performed during August and September of 1993 under United States Air Force Contract No. F33615-92-C-5936 for the Crew-Centered Cockpit Design Field Demonstration Program, Crew Systems Directorate, Armstrong Laboratory, Air Force Materiel Command, Wright-Patterson Air Force Base, Ohio. Major Julie Cohen served as the Program Manager and Mr. Philip V. Kulwicki served as the Project Engineer. Mr. Michael Rountree was the Veda Program Manager.

The industry review was conducted by Major Julie Cohen and Mr. Philip Kulwicki of the Crew Systems Directorate, Armstrong Laboratory; Mr. Michael Rountree and Mr. Edward Lehman of Veda Incorporated; and Mr. Brett Storey of Storey Consulting. This report was prepared by Mr. Edward Lehman, Mr. Michael Rountree, Mr. Brett Storey, Mr. Philip Kulwicki, and Major Julie Cohen, with the editorial assistance of Ms. Katherine Jackson.

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TABLE OF CONTENTS

Page

LIST OF TABLES

INTRODUCTION

The Air Force's Crew-Centered Cockpit Design (CCCD) Program is an advanced development effort to upgrade, demonstrate, and evaluate a crew station design process, known as the Crew-Centered System Design Process (CSDP), and its support procedures, databases, and tools. Past and present crew station designs were primarily driven by the configuration of the aircraft, and little attention was given to operability by the crew. The CSDP is intended to improve design practice, allowing designers to base decisions on mission requirements and crew capabilities while meeting installation constraints. Once it is validated, the CSDP should lead to the development of well-integrated, intuitive crew stations. A key part of this development is a computer design support system, known as the Cockpit Design System (CDS), which has a software and simulation toolset to fully support the cockpit developer's need for effective crew station analysis, design, and test. The CDS Toolset offers improved design efficiency and includes traceability functions that preserve the rationale for design decisions (e.g., automation alternatives, location of controls and displays, selection of display symbols) to guide crew station upgrades. The users are cockpit design and test teams in government and industry. The goals of the program are to structure and manage the total crew system development, provide validated tools for cockpit design and test, and ensure that crew capabilities and limitations are prominent design variables.

The CCCD Program Office recognizes that the acceptance and long-term utility of the CCCD products depend on the interest and support of the cockpit development community, which includes aircraft prime contractors (also called industry) and government aircraft acquisition organizations. For this reason, a survey of four aircraft prime contractors was made during August and September of 1993. The companies surveyed were: Northrop Advanced Technology Development Center, Lockheed Fort Worth Division, McDonnell Douglas Aerospace-East, and Lockheed Aeronautical Systems Company. This report documents the results of the survey.

The objective of the survey was to elicit end-user requirements for CCCD products, where an end-user is defined as any member of a crew system organization that will have a direct impact on the outcome of a cockpit design. The two principal organizations that are responsible for cockpit development are the aircraft manufacturers crew system groups and the System Program Office (SPO) crew system groups. An aircraft crew system group directly performs the analysis, design, and evaluation of a cockpit, while a SPO group helps to structure aircraft user (mission-specific) requirements and monitors development programs so that the cockpit will meet or exceed requirements. The two groups share several key characteristics. Both need to work with other design teams involved with air vehicle development. Both are responsible to similar higher

organizations and produce specific products. The intent of the CCCD Program is to provide a process and a toolset to assist in performing the necessary design activities with greater efficiency and increased success.

The survey was performed in two parts. First, by advance mailing, the industry review teams (reviewers) were given an Industry Review Package that contained a narrative description of the new, structured, traceable, and crew-centered process for cockpit design (Appendix) and a narrative scenario that provided additional context. After examining the narrative description and scenario, the reviewers critiqued each document by completing a questionnaire. Details of the entire survey can be found in the CCCD Interim Technical Report No. 1 (Reference 1). Second, after reviewing the completed questionnaires, an Air Force team visited each company to conduct follow-up discussions and to clarify the critiques. Following the Air Force visit, each company supplied a written final report.

The reviewers had varied experience, composition, and respective roles in the cockpit development process. A wide range of experience in differing phases of aircraft development was captured through various team experiences in Concept Exploration, Demonstration/Validation, Engineering and Manufacturing Development, and Post-Production Support.

Information was obtained from engineers, scientists, and managers who were involved in different crew station activities including pilot-vehicle interface (PVI) design, crew station design, human factors analysis, systems engineering, and operational analysis. These disciplines are representative of those found in an integrated crew system design group. Most crew system design groups in the aircraft industry appear to have formal or informal ties with the other disciplines, essentially forming Integrated Product Team (IPT)-like organizations. Only one company had formally used the IPT methodology in the crew system design area, but most have working groups who provide similar results. One of the strongest indications of the IPT-like organizational philosophy was a common recognition by survey participants that crew system groups must interface with the various disciplines that are responsible for the other aircraft systems affected by the cockpit.

The format of each visit was as follows: The Air Force team provided opening remarks and reviewed the agenda, after which all attendees introduced themselves. The agenda included summaries of the objectives and background of the CCCD Program; the evolution of the CSDP and the CDS Toolset; and the objectives, status, and background of the ongoing CCCD Field Demonstration Program. The Air Force team then conducted a question-by-question review of the

written survey responses. Finally, the group discussed typical design facility practices, the data processing environment, and prioritization of the CSDP and CDS technical objectives. Additional time was devoted to demonstrations of resident cockpit design and evaluation tools. The visits concluded with a brief discussion of major conclusions and plans for future interaction. The participation in this survey is summarized in Table 1.

Table 1. Survey Participants*

Company	Date of Visit	Number of Reviewers	Aircraft Dev Exp	Number of Attendees	Aircraft Dev Exp
Northrop Advanced Technology Development Center Pico Rivera, CA	Aug 93	5	B-2 A/FX	5	B-2 A/FX
Lockheed/Fort Worth Fort Worth, TX	Sep 93	2	F-16 F-22 A-12 A/FX	2	F-16 F-22 A-12 A/FX
McDonnell Douglas Aerospace - East (MDA-E) St Louis, MO	Sep 93	2	YF-23 F-18 F-15	2	YF-23 F-18 F-15
Lockheed Aeronautical Systems Company (LASC) Marietta, GA	Sep 93	2	A/FX JPATS	5	F-22 P-7 C-130 A/FX JPATS

* Reviewers of the CSDP narratives, who supplied the detailed critique and questionnaire results, did not correspond one-to-one with the attendees at the follow-up visit.

Overall, the participants agreed that the CCCD Program was making progress. Each company representative made specific suggestions for enhancements and emphasized features that could be valuable to both industry and government. This cooperative approach will contribute greatly to the development of a process and support tools that will improve future cockpit development projects.

COMMENTS ON THE CSDP

The data collected from the written responses and from the technical discussions at each company, along with the interviewer's interpretations, are presented in the following paragraphs. In many cases, the responses represent a consensus of opinion, although some are individual opinions.

General Comments on the CSDP

Overall Need. The reviewers generally concurred that there is value in having a uniform, accepted process for crew station development. This kind of process would foster the use of effective techniques and provide instructional material for newer project managers. A process description with more depth could also be valuable to the members of the Cockpit Design Team (design team) who are assigned to the development or modification of a cockpit.

Target Audience. Some reviewers pondered the overall purpose of the CSDP in the following manner: If the target audience consists of novice users, they may not have the requisite experience to effectively apply the CSDP. In other words, they may know the "whats," but not the "hows" of the specific procedures (see next paragraph). If the CSDP is developed for experienced users, they would know how they have developed cockpits in the past, and only the CDS Toolset would be useful. If the CSDP was meant to ensure that industry competitors have a "level playing field," it was deemed to be a worthwhile accomplishment. The conclusion is that the description should be rewritten to clarify the intended role of the CSDP.

Level of Detail. As anticipated, the reviewers requested more in-depth information about the CSDP activities. However, this additional information will be provided on an on-demand basis because the brevity of the existing CSDP was judged to be appropriate for both management users and experienced designers.

Procedure Outline. In the CSDP, each activity in the design process is accomplished by following a detailed procedure for performing the work. A sample procedure was included in the advance mailing and was reviewed during company visits. No additions, deletions, or modifications to the procedures were suggested.

Tailorability. The reviewers concurred with the objective to make the process tailorable to the time and resource limitations of an actual project. Several reviewers expressed support for tailorability in the current CSDP, asserting that it should provide a basic approach to cockpit development that

can be adapted to meet the needs of a given program. They also commented that the CSDP makes the human-centered emphasis more explicit and goes beyond other system process descriptions by emphasizing the iterative nature of the design approach.

Phasing. Several comments referred to the need to segment the CSDP by program phases, because the nature and depth of CSDP activities are heavily influenced by the maturity of the development program. The Weapon System Development Program (WSDP) phases--Concept Exploration, Demonstration/Validation, Engineering and Manufacturing Development--were discussed as one possible framework for phasing. Another possible framework that was discussed is based on different project categories. Three project categories were defined: (1) a minor change to an existing cockpit, such as an Engineering Change Proposal (ECP); (2) a major block upgrade of an existing cockpit; and (3) a totally new cockpit development effort. Regardless of the framework, it was agreed that the activities that are conducted at each of these levels tend to be similar, but the depth of the analysis (or design or test) and the proportion of time spent doing them varies greatly.

Air Force Endorsement. The reviewers urged the Air Force to incorporate the CSDP into Requests for Proposal (RFPs), Statements of Work (SOWs), and other contractual agreements. This will give the design team the necessary authority and justification to acquire the tools and funding resources needed to accomplish the process. As one reviewer stated, "Any time the Air Force can provide guidance and tools, this is desirable."

Level in Work Breakdown Structure (WBS). One reviewer described the crew system as "the poor stepchild" with respect to most other air vehicle subsystems. Several discussions at each company focused on a previous Air Force initiative to raise the crew system to a Level-3 WBS item under MIL-STD-881B, with the recommendation (at each site visit) that the Air Force pursue this initiative. While this would not appear to directly impact the development of the CSDP, it would elevate the importance of using a process like the CSDP within the overall air vehicle program, thereby enhancing the probability of its acceptance and use by industry.

Integrated Product Team (IPT). Many reviewers cited the need to relate the CSDP to the entire aircraft project. These ties should include the other engineering disciplines such as avionics, propulsion, and flight control. The CSDP is fully compatible with the IPT concept, in which Human Factors Engineering (HFE) is integral to the team.

It was pointed out that critical cockpit development milestones should be applied at the program level and integrated with all other critical milestones, to ensure that cockpit requirements and issues are addressed appropriately. Several of the reviewers were acquainted with the Air Force Crew System, System Engineering Master Schedule (SEMS), and mentioned the probable value of correlating the CSDP with the SEMS. The acquisition SPOs would use the SEMS to manage the crew system progress on major development contracts.

Extended Parallelism of Activities. Most reviewers agreed that the CSDP activities should run more concurrently throughout the developmental life cycle than was implied by the survey materials. For example, it was stated that part-task simulation tends to begin earlier than implied in the present CSDP, and that planning activities tend to continue further into the process than graphically shown. The concurrence of the activities will be modified in future CSDP revisions. However, the sequential conduct of analysis prior to design will remain intact to enable the traceability from derived requirements to implementation decisions.

Interaction and Iteration of Activities. There was widespread agreement that the CSDP would benefit both from a more explicit interaction among various crew system development activities and from a more explicit description of the iterations through the activities. A more detailed description of the application of the CDS Toolset throughout the process was also recommended.

Some reviewers remarked that the CSDP should provide guidance in determining the number of iterations of the analysis/design/evaluation cycle. Other reviewers observed that iterations are continued within time and budget constraints, as now indicated in the CSDP. The general consensus was that this practical approach is essentially the way the iterations are determined. Another suggestion was that entry and exit criteria could be addressed in the CSDP.

Assistance in Scoping Work. At one company, reviewers suggested that the CSDP should provide a basis for estimating the scope of work within the phases and activities. This estimate would be helpful for companies or organizations that have not had extensive experience in cockpit development. However, the majority of the reviewers felt that labor-hour, time, and cost data are not tracked in a manner that would permit the allocation to CSDP activities or functions.

Specific Comments on the CSDP - Phasing of the Process

The consensus among reviewers was that the CSDP is properly portrayed in the five distinct, but interactive categories of: (1) Program Planning, (2) Up-Front Analysis, (3) Crew System Analysis, (4) Crew System Design, and (5) Crew System Evaluation. By distinguishing five distinct categories, each type of activity can be coherently described and developed.

Program Planning

The description of the Program Planning category, which includes scheduling, was the smallest section of the draft CSDP document because of the focus on the technical needs of the design team. The reviewers observed that there are a few key needs that, if satisfied, would make the planning and scheduling of an integrated cockpit development effort more efficient.

Dynamic Planning Capability. The reviewers would like to be able to perform dynamic planning to accommodate frequently changing requirements. They would like to be able to project the impact of certain situations, both real and postulated and to replan both known and projected situations in order to react to ever-changing program directions. In fact, this capability may, in the long run, actually reduce the frequency of such changes because users will have the tools to predict the impacts of changes while they are still in the early, formative stages of the development phase. The CDS currently lacks this capability.

Integration with Total Program. When planning and scheduling functions are performed, the crew systems group often lacks the necessary information to plan a complete integration. A substantial amount of time is required to track down all of the information and to keep it updated to reflect changes. Without this information, cockpit designers may not complete certain tasks, or may perform them in an unplanned sequence, which could preclude an orderly integration with other subsystems. Conversely, other design groups often cannot provide the crew system group with the needed information on a timely basis. Many reviewers stated that integration at all levels, specifically technically, would be of great value, particularly given the growing use of the IPT structure. The CSDP is being revised to make interactions with other program elements more explicit.

Subcontractors and Risk/Technology Gaps. The reviewers felt that the CSDP should be set up to take into account subcontractor plans and schedules because they are critical to the integration of the cockpit. Additionally, the need to assess the risks associated with both current technology and

projected technological gaps must be introduced into the planning function of the cockpit development process. This omission was an oversight in the draft CSDP. Assessment of risks will be an integral part of the planning phase and will be essential in the technical areas of the CSDP as well.

Upwardly Compatible to Project. To enable a fully integrated planning and scheduling capability, the reviewers felt that any functionality at the crew system group level should be compatible with the company's project planning and reporting system. Typically, a project-level planning system is large, is hosted on a computer system that is not directly accessible to the crew system group, and does not easily permit data to be imported or exported. Personnel must enter the planning information into their own systems, and provide hard copy submittals for manual entry into the project-level systems. This method usually results in lost data, de-emphasis of the cockpit portions of the project plans, and duplication of effort. Ideally, the CSDP would eliminate or minimize this problem with its explicit program planning function that is supported by CDS software tools. The CDS currently lacks this capability.

Crew System Plans. One of the elements of program planning that was of marked interest to the reviewers was how the CSDP assists in the preparation of crew system plans. This preparation entails retrieving and using information that shows how to formulate necessary plans based on standard, endorsed formats, and how to apply relevant information from earlier programs. Program planning has grown more complex because of the IPT function and because of additional, new reporting requirements. The CSDP could provide useful guidance in the preparation of crew system plans.

More Description/Activities. One of the requested modifications to the Program Planning category was to add more activities that would provide a greater amount of program planning and scheduling functions. Additionally, the descriptions of current activities need to be developed before an accurate review of this category can take place.

Up-Front Analysis

The majority of the reviewers were pleased with the formal creation of a separate process category for requirement definition. Most comments on this category were positive. Several reviewers stated that this portion of the CSDP provided assistance to the already-formulated process development at their site.

New Function. The formal introduction of Up-Front Analysis to the development of the cockpit was recognized as an appropriate addition to the development cycle. Up-Front Analysis activities are usually accomplished, but are not afforded the structure implied in the CSDP. Most reviewers stated that giving more attention to requirements generation, development, and traceability at an early stage will be of benefit in subsequent stages because a more definitive set of requirements can be established and the design features can be clearly substantiated.

Name Change. Several reviewers suggested renaming the *Up-Front Analysis* category to *Requirements Definition* because the latter term is more descriptive and conveys more weight with program planning personnel. In view of the broad and variable interpretatio: ie word "requirements," this part of the CSDP was later renamed *Requirements Analysis an redesign.* This new title is used throughout the remainder of this document to refer to the category formerly known as *Up-Front Analysis.*

Interdisciplinary Trade-offs. One of the main themes that evolved as a result of the industry s vey was that more attention should be paid to working group relationships between the disciplines involved in developing the cockpit and its associated systems. The CSDP took into account a formal method of multidisciplinary systems engineering, that of an integrated design team that includes engineers from a number of disciplines. While this approach is consistent with the IPT approach advocated by the Air Force, it apparently does not reflect the prevailing organizational structure currently in use in industry today. Therefore, multidisciplined working group sessions should be shown as a requirement in the CSDP. The emphasis during the Requirements Analysis and Predesign phase will be the interpretation and trade-off of the requirements that drive the design of the cockpit and its associated subsystems, leading to the development of integrated specifications for these items.

Accommodation of Requirements Changes. The reviewers characterized cockpit requirements as highly volatile and ever-changing, and emphasized the need to accommodate these changes in the CSDP. While not specifically discussed in the Industry Review Package, requirement changes would be assessed when changes occur and the best alternative would be selected to meet the modified requirement. For example, if the requirement change was to add or subtract a capability that directly affects the aircrew's ability to perform a mission, then the analysis, design, and evaluations performed to-date may have to be repeated. In contrast, if the requirement change was to extend or degrade a capability, then only certain design elements would have to be examined for possible impacts. As a minimum, an impact assessment would be required, whether or not the

cockpit design needed to be changed. This capability will have to be more formally introduced throughout the CSDP in order to accommodate changes in requirements.

Crew System Analysis

Discussions of Crew System Analysis as a special CSDP category generated a wide range of viewpoints. Most of the reviewers remarked that the CSDP activities and sequences would be a good method for performing these analyses, but there was considerable divergence regarding the value of the analyses versus the time and effort expended.

Activity Development. The reviewers considered the analysis activities described in the Industry Review Package to be comprehensive with respect to the design of the PVI. However, the reviewers expressed a concern that the CSDP did not include enough analysis of other factors, such as life support, escape, reach, cockpit layout, canopy and structural analysis, ray tracing, and lighting analysis.

Concerns Over Time and Budget. In this phase more than the others, the reviewers were concerned with what appeared to be a drastic increase in the number of activities over those currently required and the additional time necessary to perform and document them. Many stated that they would never have the budget to support these activities in addition to the other more important design and test activities. The reviewers expressed a desire to gain experience with the CSDP and the CDS Toolset before commenting further on time and budget concerns.

Value of Certain Analyses. The value of some analyses was questioned by the reviewers. The predictive workload analysis and, to a lesser extent, the task/timeline analysis, were specifically mentioned as not providing useful information in the past. Most reviewers stated that their crew system groups include both experienced engineers and operational crew members who have knowledge of mission choke point areas and the time required to perform tasks in sequence. They further asserted that the only real reason for performing many analyses was to satisfy a Contract Data Requirements List (CDRL) deliverable.

The ability to perform analysis tasks more quickly and with more validity was received with a "show me" attitude. Several of the reviewers stated that if a valid, customer-endorsed process with practical support tools were provided, confidence in the value of these analysis activities would be improved but not assured. In the event that the military acquisition offices (e.g., SPOs) request this type of analysis, the CSDP and the CDS Toolset should expedite the work.

Iteration of Analyses with Design and Evaluation. Those reviewers who agreed with the need to perform the crew system analysis tasks suggested that the CSDP should incorporate a greater amount of iteration in the design and evaluation phases of a project. That is, more of the information developed to refine the cockpit design should flow through the iterative cycles identified in the CSDP. This could be accomplished by adding an iteration reminder to the already developed cycles.

Common Database and Data File Information. The reviewers were pleased with the fact that the CSDP was being developed so that data could be accessed for each analysis task from a common database. The reviewers saw that this information flow within and between activities of the CSDP would save time when performing various analyses. The reviewers stated that if they were required to perform the full scope of the CSDP analyses, a shared database of common information would result in tremendous time savings over the life of the project.

Crew System Design

The reviewers stated that Crew System Design is the most critical of the five CSDP categories because of the accountability that is necessary in the design of each cockpit subsystem. They also stated that the majority of the time and budget allocation is devoted to the design phase of each project.

Iteration of Design Cycles. The reviewers agreed with the design iteration aspects of the CSDP. In fact, many stated that more formal definitions of the design iterations should be developed as major facets of the detailed CSDP procedures. Each company stated that the cornerstone of development was the iteration of rapid prototyping activities, which is performed throughout design, development, and early evaluation. The reviewers felt that a greater number of completed iterations would result in a higher quality design.

Activity Development. The design portion of the CSDP was found to have a thorough layout of activities relating to the design of the PVI. However, as discussed in the Crew System Analysis section, the reviewers expressed concern that the CSDP did not sufficiently cover other factors such as life support, escape and reach, cockpit layout, canopy and structural analysis, ray tracing, and cockpit lighting.

Rapid Prototyping. Rapid prototyping was the most widely cited technique used to assist in the design and evaluation of controls and displays. Each company surveyed has a device (or devices)

that permits near-real-time representation of cockpit controls and displays. Typically, rapid prototyping simulators may lack full system functionality but have adequate responses provided in interactive simulation. The design is described in mechanization documents, which usually consist of written and graphical information about implementation concepts. The design engineers write the mechanization document and then work with software engineers to implement the designs on graphical engines such as Silicon Graphics or Sun workstations. Once working, the designs can be exercised in representative, but often rudimentary, mission tasking situations. Evaluations are then conducted, usually by members of the design team who have an operational background. The data are almost entirely subjective, and design changes are quickly made in the rapid prototyping simulator. Rapid prototyping was considered a valuable and extensively used element of industry's current process for cockpit design.

There are two areas where the CCCD approach might improve the rapid prototyping technique used by industry. The first area involves introducing methods to objectively evaluate rapidly prototyped design solutions in order to augment the current reliance on subjective, qualitative assessments. The reviewers were concerned that objective methods might impose restrictions that would limit the quickness of the process (e.g., by requiring numerous trials, multiple subjects, or extensive data analysis). If the objective methods did not unduly compromise the speed of the process, the users would agree to try them.

The second area includes the development of a prototyping system that does not overly rely on a small cadre of highly skilled programmers. Currently, the industry cockpit simulators typically rely on a few skilled programmers to implement the cockpit mechanizations; therefore, the reviewers were receptive to ideas that might lessen the impact of losing a key individual. However, since the companies already possess rapid-prototyping systems, they appear to be reluctant to endorse near-term investments in a new system (including equipment and training costs) for far-term advantages of reduced reliance on key individuals. To be useful to industry, any development in this area should be compatible with the cockpit simulators, or rapid prototyping systems, in use.

Design Trade-off Methodology. The formal design trade-off methodology within the CSDP is based on Quality Function Deployment (QFD). The basic premise is similar to classical system engineering. Both methods require engineers to perform trade-offs of capabilities versus implementation costs by weighing the importance of the trade-offs and deriving the best solutions. The QFD methodology employs a series of matrices to express the system trade-offs. The CSDP, with its design iteration cycles, depends on the effective use of trade-off methods. A few of the

reviewers were experienced (both formally and informally) in using the QFD methodology and reported that the results were useful. They stated that, while it takes considerable time to perform, ultimately the use of QFD saves time by providing a means to elicit a full description and an interpretation of the critical facets of the design. In this way, QFD forces the design team to justify the design features in terms of requirements. This justification results in more defensible, higher quality designs, and aids design traceability.

Multidisciplined Approach with CSDP. The reviewers seem receptive to a more formalized approach to guide the operation of inter-disciplinary working groups. Since each company has varied organizational structures, it was suggested that the CSDP formally recognize the use of multidisciplined working groups. Those organizations using IPTs would benefit from the explicit recognition of working groups within the CSDP to emphasize the IPT function. The emphasis, especially while doing design work on the CSDP, will be on the trade-off of the evolving requirements against the implementation impacts, which will drive the cockpit and all associated subsystems. The product will be a single integrated design for the crew station (including avionics, structures, and PVI) that is expressed in the mechanization documents and specifications.

Mechanizing the Pilot-Vehicle Interface. The reviewers were engineers with diverse backgrounds in various aspects of cockpit design. Some of them were responsible for designing controls and displays and writing the required specifications for implementation. Others were only contributors to the design and implementation. In all cases, however, the engineers seemed to require some assistance with the detailed description of system interfaces within the cockpit. The discussions focused on the ability to "speak the same language" as the subsystem engineers and the software engineers when discussing either simulation or actual system implementation. The CSDP supports these functions through the use of mechanization logic diagrams to prepare both the designs and the specifications necessary to implement the design interfaces. Several of the reviewers have used mechanization logic trees and reported success in getting designs implemented and documented properly. All were in favor of the inclusion and exploitation of mechanization logic trees for the development of controls and displays.

Traceability of Design. The CSDP requirement for design traceability left the reviewers leery. The discussions centered on the actual need for tracing the rationale and history of cockpit design features (versus the current practice of tracing requirements, rather than design decisions, as part of configuration management). The reviewers would welcome a better definition of how much detail the government wants to see in traceability documentation.

Most companies will be providing cockpit design traceability information for the SPOs. Given the choice, the companies would not produce more than current documentation requirements, which consist of cockpit specifications, CDRL submittals, and working group notes. When the government team clarified that the CSDP traceability approach would enable them to trace specific requirements through design implementation and test verification, the reviewers seemed to be encouraged that such an approach would be useful if it did not impose the significant burden of additional documentation.

The specifics of requirements traceability seem to be limited to the "top" and "medium" levels of the design. This allows for traceability to be handled both at a major functional level (e.g., why a certain number of displays are needed), as well as at a medium level (e.g., why targeting information on all displays looks the way it does). The reviewers did not want to go to the lowest level (e.g., why certain symbology was selected, or why a routine switch is configured a certain way), because of the multitude of minor changes that are usually made, and the sheer number of items within a cockpit. They indicated that little would be gained by tracing the design to the lowest level. The reviewers requested that documentation requirements for traceability be kept to a minimum, and not require tracing to the component level.

There was apparent skepticism that the CSDP emphasis on traceability would greatly enhance the ability to control cockpit designs. However, the reviewers noted that such traceability records would assist the company in defending its current design by establishing a direct, logical connection between mission requirements and system features. Additionally, the reviewers agreed that traceability records would provide a design history database to filter the suggestions submitted by engineers who are new to the project. The records could be used to eliminate proposed enhancements that were tried before, or that simply do not meet the requirements trail as it has developed. Finally, the reviewers acknowledged the value of recording (and being able to retrieve) the traceability information for use in cockpit modification programs (e.g., block changes).

Crew System Evaluation

Based on the survey, the Crew System Evaluation category of the CSDP requires the least amount of modification. However, when the reviewers were asked specifically about improving the evaluation process and ensuring the validity of this portion of the CSDP, they provided the insights that follow.

Simulation and Rapid Prototyping for Cockpit Evaluation. The overwhelming finding with regard to the Crew System Evaluation category was that the companies use several types of interactive Pilot-in-the-Loop (PIL) simulation. The types of PIL simulation in use are: rapid prototyping, part-task, full-task, and part-mission testing. Each company expressed confidence in the ability to test PVI functions within each category of PIL testing. Each uses a combination of subjective and objective performance measures, but the great majority of the evaluations are done subjectively. One company has implemented physiological monitoring systems. The actual benefit of these evaluations does not seem to be as clear as the ability to perform them. That is, all companies felt confident that their methods of planning and conducting cockpit simulator studies were well thought-out, but the results from the studies were not as conclusive as desired. In summary, the current usage relies primarily on subjective evaluation of the cockpit with little use of quantitative simulation results for making design judgments.

The subject of rapid prototyping evaluation was enthusiastically discussed because all companies found this activity to be the most prominent and useful technique for design evaluation of the PVI. Rapid prototyping provides a relatively quick and inexpensive way to present design ideas to the operational aircrews and design engineers. The bulk of the testing is conducted informally and typically elicits the subjective opinions of aircrew personnel from several sources, such as the design team, the overall project personnel, and the customer. The reviewers seem to be satisfied with the results of these evaluations because they can quickly resolve PVI issues prior to beginning expensive software development for higher fidelity simulation (i.e., dome simulators or avionics hot benches). Rapid prototyping also furnishes an easy and affordable way to develop traceability of the PVI design and to help document user acceptance.

The ability to plan and perform all types of PIL simulator evaluation was claimed by each of the companies. The majority of the reviewers had previously used objective and subjective measures to evaluate crew performance, workload, and situation awareness within the cockpit. Some had performed PIL simulations with physiological measures to augment the other data, and others had used derived Measures of Effectiveness (MOEs), such as calculations of lethality and survivability, associated with the type of aircraft under development. In summary, most of the evaluators concluded that the best evaluation measures were formal subjective comments obtained directly from the aircrews, even though objective test data had been collected. The reviewers agreed that, in current industry practice, the subjective comments of the aircrews have the greatest impact on design changes.

With respect to a simulation test planning capability within the CSDP, the majority of the reviewers wanted to know more about what would be available and how it would be used. A SPO-endorsed planning capability for PIL-based evaluations seemed attractive. It was explained that the test planning function would provide the capability to plan any type of PIL evaluation with an appropriate set of measures, metrics, and reporting techniques advocated by the government. Moreover, a database of additional information regarding the specifics of test set-up, training, operations, and data analysis techniques could be accessed when required. Finally, it was recognized that it would be advantageous to use the same test planning methods for both simulation test and flight test.

Reliance Upon Software Engineers. Industry's current ability to perform most PIL evaluations seems to rely on a small cadre of software engineers who know how to rapidly configure the PIL simulator (see Rapid Prototyping-Crew System Design section). Occasionally, the software personnel are assisted by hardware engineers, but the reconfiguration is done almost exclusively in the software group. All reviewers admitted that the loss of one or two key programmers could essentially bring a cockpit project to a halt. When asked if they would use a more software-independent method of designing and prototyping displays and controls, if available, the reviewers replied that they would rather continue the current methods than invest in another type of system.

On the other hand, the reviewers agreed that the matter of simulator construction, operation, and maintenance is best left in the capable hands of simulation departments. The reviewers noted that current simulator operations make the best use of the company assets and do not inhibit crew station designers from planning and performing the needed PIL tests. Typically, simulator assets are shared with other disciplines such as avionics, operations analysis, systems engineering, flight controls, marketing, public relations, and others. However, the design team usually performs the lead role in the simulator cockpit evaluations; an exception is the detailed design of the flight control system, which is usually handled by the flight controls group.

Other Testing Activities. Several of the reviewers pointed out that the CSDP did not adequately depict the nature of crew system evaluations in the areas of cockpit accommodation (seating, egress, reach, vision), life support, escape, and lighting. Many of these areas are typically subcontracted and the associated verification testing is often accomplished in the subcontractor facility or in a system integration or avionics integration laboratory over which the design team has little control. The ramifications of these evaluations could drastically alter cockpit development and should be included in the design trade-off and iteration cycle, and should be recognized during early program planning.

Evaluation Timing. Some companies suggested that the CSDP should call for the earlier use of evaluation and simulation to support the process of the cockpit (and air vehicle) specification. (Note that "simulation" in this context refers only to real-time, PIL simulation.) The reviewers asserted that early in the process, the requirements analysis and design efforts often begin simultaneously, so that simulation activities occur much sooner than presently shown. This would appear to be more the case for Concept Exploration than for later phases. The reviewers also remarked that simulation as a means of investigating excursions from the specified aircraft requirements would be useful for the CSDP.

The reviewers agreed that an evaluation of the crew station, early in the design cycle, would help to bring problems to the surface, and would allow time for correction. Using the CSDP, this evaluation is a formal part of the crew-centered methodology under which the cockpit design follows a controlled evaluation. This evaluation starts with requirements development, continues with analysis and design, and ends by verifying that the requirements were met. The need for early cockpit evaluation must be tempered by the need for an orderly, controlled, and traceable process that can be used to produce a dependable cockpit design.

Prioritization of Cockpit Design Objectives

The reviewers were presented with a list of 22 candidate objectives of the CCCD Program. They were asked to rank each objective from one (most important) to five (least important) and to mark the three most important objectives with asterisks (*) and the three least important with checks (√). The objectives, and the quantitative results obtained from the reviewers, are listed in Table 2 in the same order as they were presented to the reviewers. The number of ratings per objective varies in several cases because some reviewers opted not to prioritize some objectives.

Several of the objectives are quite general, with no direct connection to specific aspects of the CSDP or the CDS Toolset. For example, the reviewers consistently prioritized *Ensure safety in cockpit design* as an important objective. However, the reviewers stated that cockpit safety is a "motherhood" concern that is always given top billing, but has no direct implication for the process or the tools. Therefore, the objectives listed in Table 3 have not been included in the remainder of this report because they do not require specific upgrades of the CSDP or the CDS Toolset.

Table 2. Objectives and Priorities from Survey Ratings

Ratings	Objectives	Average
*1,*1,2,1,*1,1,2,*1,*1,2	Translate mission requirements into cockpit design constraints.	1.3
*1,*1,2,1,*1,3,*1,*1,1	Emphasize crew capabilities in cockpit design.	1.3
*1,*1,*1,1,1,1,2,1,2,*1	Ensure safety in cockpit design.	1.2
3,2,4,4,*1,*1,4,2,*1,1	Trace the decisions that led to a cockpit design.	2.3
3,2,*1,3,3,2,2,*1,3,2	Control the configuration of various cockpit designs.	2.2
3,√5,3,*1,3,3,*1,3,2,2	Visualize design alternatives interactively.	2.6
3,3,*1,2,2,1,2,2,2,2	Compare cockpit alternatives to a baseline cockpit.	1.9
3,2,3,2,3,3,*1,2,3,√3	Modify and evaluate cockpit designs in a matter of days.	2.5
3,2,4,2,3,2,*1,2,2,*1	Minimize the cost of each cockpit design iteration.	2.2
3,2,*1,2,3,1,3,2,1,*1	Maximize the quality of each cockpit design iteration.	1.9
2,4,3,*1,1,3,4,3,2,1	Apply validated and accepted procedures to cockpit design.	2.4
2,√4,5,1,*1,2,√4,3,2,1	Use of standardized, comparable measures of cockpit design characteristics.	2.5
3,3,5,2,3,4,3,4,2,2	Provide an integrated suite of design tools to assist with cockpit design.	3.0
√3,√4,4,3,√5,3,1,2,3,2	Minimize purchase/maintenance cost of hardware and software tools.	3.0
3,2,2,4,1,√4,3,1,4,2	Provide a communications medium for a cockpit design team.	2.6
2,4,√5,4,3,2,3,√5,3,2	Store design data and lessons-learned in a central repository.	3.3
√3,3,3,√5,√5,√4,2,3,√5,√3	Reduce reliance upon external resources during cockpit design.	3.6
3,3,2,3,4,3,3,4,3,2	Aid the preparation of design documents, specifications, and reports.	3.0
√3,2,*1,4,3,3,5,3,4,2	Aid the scheduling of analysis, design, test activities for cockpit projects.	3.0
3,2,4,√5,4,3,5,2,√4,2	Facilitate preparation of labor estimates for crew system design projects.	3.4
3,3,√5,√5,√5,√4,√4,√4,√5,√3	Depict a graphical status of the cockpit design project.	4.1
1,3,2,2,2,√4,√4,2,2	Organize operational knowledge in an easy-to-understand and use format.	2.4

Table 3. Objectives Which Do Not Require Upgrades

Ensure safety in cockpit design.
Maximize the quality of each cockpit design iteration.
Compare cockpit alternatives to a baseline cockpit.
Reduce reliance upon external resources during cockpit design.

Elimination of the four general objectives listed in Table 3 results in the list of objectives provided in Table 4. The objectives in Table 4 are listed in descending order of importance as they were ranked by the reviewers. The additional discriminators (asterisks and check marks) were used as "tie breakers" to order the closely ranked objectives.

Table 4. Objectives in Descending Order of Importance

Translate mission requirements into cockpit design constraints.
Emphasize crew capabilities in cockpit design.
Control the configuration of various cockpit designs.
Minimize the cost of each cockpit design iteration.
Trace the decisions that led to a cockpit design.
Apply validated and accepted procedures to cockpit design.
Organize operational knowledge in an easy-to-understand and use format.
Modify and evaluate cockpit designs in a matter of days.
Use of standardized, comparable measures of cockpit design characteristics.
Visualize design alternatives interactively.
Provide a communications medium for a cockpit design team.
Aid the scheduling of analysis, design, test activities for cockpit projects.
Aid the preparation of design documents, specifications, and reports.
Provide an integrated suite of design tools to assist with cockpit design.
Minimize purchase/maintenance cost of hardware and software tools.
Store design data and lessons-learned in a central repository.
Facilitate preparation of labor estimates for crew system design projects.
Depict a graphical status of the cockpit design project.

Summary of the CSDP Review

The results of the prioritization offer meaningful insights into probable needs of industry, subject to two caveats. First, the rankings were done prior to the industry site visits. Time did not permit giving the reviewers an opportunity to revise the rankings after hearing the extensive discussion of the CCCD Program objectives and accomplishments to-date. It is likely that the additional information could have influenced the ratings. Second, the personnel who attended the on-site reviews often did so in lieu of, or in addition to, the personnel who reviewed the Industry Review Package. For example, at one company the reviewers who were present at the on-site meeting emphasized the need for standard measures and metrics. However, the two "package" reviewers (who could not attend the meeting) had placed low priority on this objective. Such differences of opinion are not reflected in the above ratings that are based solely on written responses to the Industry Review Package. These ratings will be considered in future CDS upgrade plans.

CDS TOOLSET

Brief summaries describing the proposed CDS Toolset were given to the reviewers as part of the Industry Review Package. Details about the functions of the tools were intentionally omitted so as not to bias the reviewers' consideration of tool utility. As expected, many of the reviewers requested more information on the functions and capabilities of the tools. A few of the reviewers suggested that a videotape presentation would be useful to highlight the tools and to show how they support CSDP activities.

The reviewers were asked to prioritize the CDS tools. An interesting and unanticipated aspect of this prioritization was that some reviewers ranked the tools according to their organization's *need* for that tool, rather than for the *importance* of the tool in supporting the development process. That is, some reviewers ranked a tool lower if it was similar to one that they already have, and ranked another tool higher if it was one that their organization needs. This approach to prioritization was taken into consideration when analyzing the results.

General Comments on the CDS Toolset

Several comments obtained during the survey apply generally to all of the CDS Toolset. These comments are summarized below.

Tool Validation. An extensive discussion centered on the validation of the CDS Toolset. One reviewer indicated that the CCCD Program would be providing a valuable resource to the design community if it produced an established, consistent means to validate candidate tools. He suggested that the data files from the ongoing CCCD Field Demonstrations or other validation activities be preserved and distributed to serve as a basis for future evaluations. It was recognized that, while this may be a good idea in principle, differences in tool interfaces may make it impractical.

Piecewise Development. It was agreed that, while an integrated toolset might be ideal, a piecewise approach to the development of the tools should be considered, particularly in view of the current defense funding environment. This opinion was borne out by the relatively low priority given to the CDS objective *Provide an integrated suite of design tools to assist with cockpit design.*

User Interface. Given the widespread support for a piecewise development, reviewers acknowledged that the user interface may vary from tool to tool. However, the desire for effective, user-friendly interfaces was unanimous. Intuitive, easy-to-learn interfaces were requested to minimize training on new systems. One reviewer stated that he would expect, as a minimum, a twofold payback on the time spent learning a new tool.

Several companies balanced their desire for user-friendly interfaces with a strong desire for functionality. They explained that if a tool offers a useful capability but a somewhat cumbersome interface, it will be used nonetheless. At some point the problems with usage will outweigh the advantages and the tool will no longer be used. It seems clear that the CDS Toolset will be used, in spite of a suboptimal interface, if it provides the design community with useful, effective support.

Global Relational Database. Most reviewers suggested that all tools share a common relational database. This suggestion is reflected by the high priorities given to the objectives *Trace the decisions that led to a cockpit design* (priority of 2.3) and *Provide a communications medium for a cockpit design team* (priority of 2.6). The availability of a common database would also help to meet the objectives of *Modify and evaluate cockpit designs in a matter of days* (priority of 2.5), and *Aid in the preparation of design documents, specifications, and reports* (priority of 3.0). It is also closely related to the ability to *Store design data and lessons-learned in a central repository* (priority of 3.3).

Program Planning and Scheduling Tool (PPST)

The CDS objective that is directly related to the PPST is *Aid the scheduling of analysis, design, test activities for cockpit projects.* This objective was given an aggregate priority of 3 on a scale of 5 (with 5 being low priority) by the personnel surveyed. There are two reasons for this relatively low priority.

First, airframe manufacturers use powerful and complex program planning and scheduling tools, for example, Artemis, a commercial software product, and the Integrated Master Information Control System (IMICS) by McDonnell Douglas. Usually, because of the complexity of these tools, the planning and scheduling inputs are made by specially-trained personnel. That is, crew station inputs are furnished to the trained operators who perform data entry and provide the planning analysis reports. Second, on small projects, PC-based tools (typically MacProject and MacSchedule) have been found to be satisfactory. The reviewers preferred commercial off-the-shelf products, and gave PPST a relatively low priority.

The reviewers remarked that automated assistance in program planning is unnecessary because program planning personnel already know how to prepare schedules. Several reviewers stated that a major concern with automated planning systems is the burden of maintaining the database of reference information and the difficulty and costliness of data entry. One feature of a planning and scheduling tool regarded as useful would be the capability to permit users to exchange PPST files with the existing corporate planning software. However, because of the variety of corporate planning systems now in use, the development of such a tool was not considered a high priority for the CDS.

Simulation Test Planning Tool (STPT)

The CDS objective *Aid the scheduling of analysis, design, test activities for cockpit projects* (priority of 3) applies to this tool as well as the PPST. Two other objectives relate to this tool: *Use of standardized, comparable measures of cockpit design characteristics* and *Store design data and lessons-learned in a central repository*.

The reviewers gave the test-planning functionality of the STPT a low priority because it is their contention that they already understand how to plan simulation tests, including the selection and definition of the tests and the required resources. The STPT was characterized as a "nice-to-have" tool, but one that is nonessential. However, several reviewers requested lessons-learned data

about specific measures that would be a feature of the STPT, and would relate directly to the objective *Use of standardized, comparable measures of cockpit design characteristics* (priority of 2.5). This priority of 2.5 was given in the written review and appeared to be ranked higher after face-to-face discussions. This feature would also relate to *Store design data and lessons-learned in a central repository* (priority of 3.3).

The reviewers also expressed an interest in having access to standard procedures for evaluating cockpit features using PIL simulation. These procedures might be similar to the Structured Test Procedures for flight testing contained in the Test Planning, Analysis, and Evaluation workstation that was developed (separately from the CDS) for the CCCD Program.

Cockpit Product Tool (CPT)

The reviewers expressed moderate interest in the CPT, if it could: (1) provide assistance in defining products and deliverables; (2) provide assistance in generating products and deliverables; and (3) inter-operate with the corporate document preparation systems. A priority of 3.0 was given to the objective *Aid preparation of design documents, specifications, and reports*.

The Computer-Aided Acquisition and Logistics System (CALS) initiative did not appear to have a significant impact on the requirements for a CPT, perhaps because CALS has had little or no extension to cockpit projects, to date. Only one manufacturer showed an awareness of CALS and the implications of CALS compliance. It has been reported that, while only a few CALS sites are now operational, more than 240 CALS sites will be operational by 1995 to help industry cut costs and manage work better (Reference 2).

The current software tools for documentation were regarded as adequate by the reviewers. The PC-based and Macintosh-based tools such as Microsoft Word, MacDraw, MacSchedule, PowerPoint, and Excel are often used. However, the ability to import and integrate data from the analysis and evaluation tools was considered an important function of a CPT.

One reviewer stated that design teams usually are not responsible for CDRL reports and that this tends to limit the perceived importance of a CPT. He stated that the CPT would be a valued addition if it fostered the definition and generation of cockpit products such as the Cockpit Mechanization Document.

Design Traceability Manager (DTM)

The CDS description provided in the Industry Review Package did not describe the DTM design and functionality. During the visits, however, the essential features of DTM were described, namely, a graphical depiction of the CSDP; the ability to launch many of the CDS tools; an electronic logbook; and the ability to trace design decisions. Many of the present and planned features of the DTM, such as the ability to manage project contexts, were not discussed. Context management would relate to industry's highly prioritized requirement to *Control the configuration of various cockpit designs* (priority of 2.2).

There was a strong interest in the DTM features. This interest stemmed mainly from the DTM traceability feature, as reflected in the high priority given to the objective *Trace the decisions that led to a cockpit design* (priority of 2.3). In specifying the requirements for traceability, reviewers expressed concern about levying additional reporting requirements on the developer. The reviewers seemed to be uncertain about how the traceability data would be used to determine what aspects of the design to track. For example, should the rationale behind individual symbols be traced, or should formats be displayed in their entirety? Simulation reports often document the rationale behind decisions, but it was noted that these reports are not readily accessible to the design team.

All reviewers were aware of the government interest in design traceability and it was understood that the Air Force SPOs advise using traceability management in the CDS development. The reviewers emphasized a need for a general-purpose relational database that can retain cockpit design data and make it readily available to the design team.

At one company, a commercial software product from Ascent Logic, Incorporated (RDD-100) was being examined and the reviewers mentioned that it may be similar to the DTM software. Following a demonstration, it appeared that the RDD-100 software was more appropriate for use in requirements traceability than design traceability. This software also had features that would not be required in the DTM.

Concept Mapping Tool (CMT)

The technique of concept mapping and the tool to support it (Reference 3) received interest during the review. This interest was manifested in the high priority given to *Organize operational knowledge in an easy-to-understand and easy-to-use format* (priority of 2.4). The reviewers

expressed a need for a method to achieve concurrence among Subject Matter Experts (SMEs) for operational requirements, which would be supported by the concept-mapping technique and tool. In addition, the reviewers responded positively when asked if it would be advantageous to feed a timeline-generation process with the results of the concept mapping of cockpit tasks.

The majority of the reviewers were not familiar with concept mapping as a cockpit design technique. Those personnel familiar with concept mapping were skeptical about its value. They found the results from its use to be dependent on the person performing the interview and analysis.

Overall, the conclusion was that concept mapping as both a tool and a technique would be useful, particularly early in a project as a means of clarifying operational requirements, but those results must be used wisely. It was also agreed that concept mapping would have particular value as an "introductory tool" early in the project, to acquaint human factors and system design personnel with operational procedures and issues. The reviewers expressed an interest in the developmental status and availability of the Tool for Automated Knowledge Engineering (TAKE, Reference 3), which is currently used in the CDS, and remains under development in the Armstrong Laboratory's Crew System Integration Branch (AL/CFHI).

Mission Decomposition Tool (MDTOOL)

Several of the companies surveyed expressed a strong interest in MDTOOL as a means of describing the mission and decomposing it to the event level. This interest is indicated by the high priority given to *Translate mission requirements into cockpit design constraints* (priority of 1.2).

One company expressed interest in a mission decomposition tool that could handle Battlefield Air Interdiction, Offensive Counter Air, and several other types of missions. The reviewers felt that MDTOOL would improve the purely manual techniques that are now used. The reviewers felt that mission engagement models, such as TAC BRAWLER, were too complicated and too powerful for the mission decomposition that is needed for the CSDP.

Little interest was shown in the simulation-set-up feature of MDTOOL. This was probably due to the idiosyncrasies of each simulator and the availability of existing setup tools for many simulators. The reviewers noted the benefit of sensor events such as detection, tracking, and launch within MDTOOL as a function of conditions such as weather, terrain obscuration, and electronic countermeasures (ECM). Assistance with analyzing "what-ifs" was also desired, but it was not clear if this requirement is entirely a cockpit development issue.

Design Trade-off Tool (DTT)

During the industry visits, the DTT was described as a tool that can be used to perform QFD (Quality Functional Deployment). The reviewers had relatively little knowledge of QFD and there was substantial interest in learning more about this approach, the QFD Designer software, and how these tools could support the crew system development process. This interest is reflected by the priority of 1.9 given to the *Maximize the quality of each cockpit design iteration* objective. Most of the companies already use a matrix-type approach to evaluate design trades, but do not use the formal QFD method. The companies use commercial spreadsheet programs, such as Excel, to support their current process.

One reviewer stated that his company uses part of the QFD approach to evaluate design trade-offs. He reported that weighted matrices are used, but that the effort does not currently progress through the "House of Quality" formality within QFD. The QFD approach was viewed as a means to accomplish the difficult tasks of establishing criteria, weights, and interactions early in the development process. Those matrices would then foster faster and earlier decision making. The reviewers agreed that a valuable means of substantiating design decisions would be to be able to enter the results from the QFD tool into the design traceability function.

Mechanization Logic Tree Tool (MLTT)

There was no CDS objective that related directly to the prioritization of a tool to assist in the preparation of the cockpit mechanization logic. The objective *Aid preparation of design documents, specifications, and reports* (priority of 3.0) is perhaps the most germane.

The site visits revealed the need for two categories of logic-rendering tools. The first category comprises simple tools to express a functional flow in terms that the engineer or pilot can use to represent control and display logic. If/then/else, case, and state diagrams would be included. The second category comprises tools to specify the avionic software and hardware design, including data dictionaries, consistency checks, and data flow diagrams.

The reviewers agreed that only the first category of capabilities would be used by the design team. The second category would be used by avionics specialists and programmers, not crew station designers. At one company, the reviewers cited the I-Logix Statemate software as being in the second category and agreed that it would be too complex for use by the design team.

The majority of reviewers indicated that they currently do not have tools for mechanization logic preparation and therefore gave high priority to the development of a mechanization logic tool. Currently, the mechanization documents (when formally prepared) are text descriptions of information derived from design specifications and supplemented by information derived from listings of the simulator software code.

The reviewers noted that some of the newer versions of control and display prototyping tools, such as the latest version of the Virtual Avionics Prototyping System (VAPS), can generate Ada or C code. This code can then be processed by a reverse engineering tool to provide flowcharts or other expressions of code logic. This would appear to be a cumbersome, but possibly useful means of obtaining logic specifications. While there seems to be possible value in the automatic generation of code, its clear use for crew station design appears unproven.

Several reviewers emphasized the need to provide a specification to programmers prior to beginning code development. Currently, programmers are provided only a two or three page text description, but may not be provided flow charts. Agreement was reached that it would be useful to have a tool such as MLTT to provide programmers with additional material in the form of flow charts and to serve as a guide to the controls and displays prototyping process.

The reviewers agreed that it would be advantageous to electronically export the early logic specifications from the design team to the system used by the avionics engineers. Several reviewers identified the need for MLTT to assist in integrating the cockpit control and display logic into the aircraft, including the air vehicle bus data. Often the cockpit designers assume the availability of data and controls that the avionics engineers later find difficult or impossible to provide.

Timeline Management Tool (TMT)

During the survey, the TMT was presented as an aggregation of several of the tools that were separately identified in the Industry Review Package. These tools included: the Information and Control Requirements Analysis Tool (ICRAT), the Function Flow Analysis Tool (FFAT), and the Function Allocation Trade Analysis Tool (FATAT). These tools permit the analyst to populate a mission timeline with functions and tasks (or whatever taxonomy is most appropriate) and to extract information and control requirements. Additionally, the populated timeline can be used as input to taskload and workload prediction tools.

Much of the discussion during the industry visits focused on the utility and validity of the timeline analysis functions. The reviewers gave high ratings to the CDS objectives that relate to TMT. These objectives include: *Translate mission requirements into cockpit design constraints* (priority of 1.3); *Emphasize crew capabilities in cockpit design* (priority of 1.3); *Compare cockpit alternatives to a baseline cockpit* (priority of 1.9); and *Minimize the cost of each cockpit design iteration* (priority of 2.2). While there was a perceived need for timeline information, the reviewers expressed reservations about the utility and validity of timeline analysis. The interest in timeline analysis tools was divided generally according to the reviewers' backgrounds. Human factors personnel tended to support the use of timeline analysis, while operational analysts tended to favor subjective evaluations over analytical techniques.

Several human factors analysts stated that if the task timeline analysis tool was proven to be reliable, they would use it. As one individual said, anything that helps with "crunching" the data and ranking alternatives (to screen the most promising concepts for subsequent simulation) would be useful. The industry approach to evaluation was generally described by most reviewers as essentially subjective and qualitative in nature. While they were sometimes criticized for this approach by managers, several operational analysts were adamant that nothing practical could be developed based upon quantitative, objective data. They tended to have little use for predictive analysis, favoring analysis of experiential data. However, several operational analysts supported the use of timeline analysis as a means of function allocation and information requirements analysis.

In summary, it appears that there is a need for valid and reliable timeline analysis tools, and that in the past, such tools were less than satisfactory. Human factors engineers appear to be willing and eager to apply timeline analysis tools if they are endorsed by the customer and if timeline analysis activities are supported by management.

Workload Analysis Tool (WAT)

Many reviewers see the measurement of pilot and crew workload as a major challenge because there is no accepted set of measures or techniques. Among the reviewers, the analytic predictability of workload was widely questioned by the operational analysts. The analysts stated that, while subjective assessment is often criticized, it remains the only suitable way to estimate workload at the present time because of the absence of other valid, accepted techniques.

On most major aircraft programs, the crew system analysts do not attempt to predict workload using quantitative analytical techniques. Instead, pilots are given representations of the mission (event timelines, task timelines, and cockpit concepts in static or dynamic forms) and are asked to assess the projected workload. When PIL simulators are available, performance is usually judged using time and accuracy measures. Workload is then assumed to be acceptable as long as performance is satisfactory, and the subjective assessment of performance is also acceptable. The Subjective Workload Assessment Technique (SWAT) is sometimes used and is an effective means of treating subjective data in a quantitative fashion, but simulator pilots sometimes complain about its intrusiveness.

As with the timeline analysis tools, the majority of human factors analysts surveyed recognize the need for valid and acceptable measures of predicted workload. One individual referred to workload analysis tools as a "necessary evil." Workload is frequently cited as a major cockpit design driver and, without a reliable measure of this design parameter, the design team is unable to identify an effective cockpit design early in the development process. The areas of workload prediction and measurement are important, and tools that support workload assessment were considered necessary for the CDS.

The reviewers suggested that the integration of the workload analysis tool with the timeline analysis tool would provide an efficient and useful basis for analyzing workload. None of the companies indicated that they have found an existing workload analysis tool that is acceptable. In several cases, a discussion of Sequitur's Workload Analysis System (SWAS) was initiated. The SWAS is a commercial software tool that estimates the amount of workload based on the time available for individual aircrew tasks versus the time required to perform them. The reviewers had little knowledge of SWAS (one company had used the software in an aircraft development program), and they expressed a guarded interest in its use. The design community is clearly awaiting reasonable proof that SWAS, or any workload analysis tool, is a valid and acceptable solution to workload and timeline analyses requirements.

Crew Station Geometry Tool (CSGT)

The companies have established computer-aided design (CAD) capabilities for crew station geometry design and specification. The tools include CATIA (trade name for the Dassault CAD/CAM package), Vision, Computer-Aided Design and Manufacturing (CADAM), Mechanical Computer-Aided Design (MCAD), and others. While these tools require trained operators, they seem to provide the necessary support for the cockpit development process. Other cockpit

geometry-related analyses, such as ray tracing (for vision assessment) and canopy reflection are also currently performed using complex tools that require trained operators. Because most of the companies use their own established systems, they see no need for the CCCD Program to develop a new tool.

Computerized Biomechanical Man Model (COMBIMAN)

The review indicated a marginal interest in COMBIMAN as a CDS tool. Several reviewers stated that they seldom design totally new cockpits and would have limited use for an anthropometric tool. The need in this area is satisfied by entering the anthropometric dimensions into a Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system to confirm reachability and clearance. Static mockups (discussed in the following section) are used to augment the CAD/CAM analyses.

Some reviewers had used earlier versions of COMBIMAN and reported problems possibly related to its having been compiled for an older mainframe computer. Interest was expressed in learning more about the latest version of COMBIMAN, which operates under CAD software using a UNIX workstation. The reviewers identified the need for bivariate or multivariate analysis capabilities, and were interested in any tool that would provide that support. The emerging standard from the Society of Automotive Engineering (SAE), to ensure compatibility and transferability across biomechanical models, was also discussed.

An anthropometric model is a necessary component of a complete cockpit development toolset, and COMBIMAN is the anthropometric model of choice for the CDS Toolset. In light of the above information, it appears that no additional development of COMBIMAN is needed for its use in the CDS, but some integration of the model within the CDS Toolset may be necessary.

Control and Display Development Tool (CDDT)

The companies surveyed already have, or are currently developing, control and display development (rapid prototyping) tools. While there are commercial off-the-shelf systems available, none has been found to be fully acceptable by any of the companies. Instead, the companies have chosen to implement custom solutions using the C or C++ languages, typically running on Silicon Graphics processors. These custom systems have proven to be useful tools, capable of providing rapid response to short-term needs.

In each company, the major drawback of the existing CDDTs was the need for skilled programmers who are knowledgeable in the software and its libraries of cockpit elements. One company described these engineers as possessing unique capabilities not only in programming, but also in cockpit design (because of the amount of work done in this area over time).

Like the anthropometric model, the CDDT is a necessary component of the CDS Toolset. The CDDT will be used to perform cockpit studies and to validate the other CDS tools. It is clear, from the industry comments, that widespread interest in a new CDDT will result if the reliance on skilled programmers can be substantially reduced. It is expected that the eventual industry users of the CDS would prefer to adapt the existing tools (rather than replacing them with new software), in part to retain commonality with the data from previous tool usage.

Part-Task/Part-Mission Simulators

The value of the part-task/part-mission simulator as an evaluation tool was emphasized by the reviewers. All of the participating companies already possess combinations of full-task or part-mission/part-task simulators, some of which are tied to rapid-prototyping systems. The use of these simulators is directly dependent on a number of skilled software engineers. There does not appear to be a high level of interest in acquiring new or different simulators unless this dependency on specialized software engineers can be significantly reduced.

The reviewers generally indicated that they would find little use for hardware-reconfigurable ("erector set") simulators. For totally new cockpits, the companies develop low-cost, static mockups featuring plywood and cardboard frames with foam core-based overlays of control and display panels. These mockups can be generated by the CAD/CAM systems and attached with Velcro or glue. The CAD/CAM renderings of the geometry are used to create the mockup panels and to analyze crew ingress and emergency egress. Designers also use the mockups to elicit opinions from pilots on the control and display geometry. In later phases of development, the mockup is often used as a framework to house controls and displays. The mechanization of these displays is usually done using the rapid prototyping systems previously described. In the latter phases of development, when an existing cockpit is available, there is no need for hardware reconfigurability because the geometry has been firmly established.

Some reviewers indicated that hardware-reconfigurable simulators are useful in a laboratory setting in which many different geometric arrangements must be evaluated in a succession of studies. One reviewer stated that if hardware-reconfigurable simulators enabled infinite placement capabilities,

they might be more useful, but that positioning of controls and displays is normally too constrained to make this capability important.

In summary, extensive development of a new cockpit simulator, as part of an industry version of the CDS, does not appear to be warranted because of the limited interest in such a simulator by industry, and because previously established cockpit simulators fulfill the needs of cockpit design teams. Currently, the CDS uses a hardware-reconfigurable cockpit simulator (the Engineering Design Simulator, or EDSIM) to verify the utility of both the CSDP and the CDS Toolset.

PROCESSING ENVIRONMENT

The companies surveyed indicated a strong desire to have a personal computer (PC), Macintosh computer, or engineering workstation for each design team member. The prevalent processing environment in industry today is characterized by a heterogeneous mixture of IBM-compatible PCs, Macintosh computers, Silicon Graphics Incorporated (SGI) workstations, and Sun workstations.

The need to share data files was emphasized. The preferred solution is a client/server architecture in which PCs, Macintoshes and workstations are networked to shared resources. The central feature of the network is one or more file servers, which permit the sharing of project files among the design team members. The network typically would provide shared access to printers, modems, and other peripheral devices.

The SGI processors seem to be preferred as simulator hosts for cockpit control and display prototyping. For example, an Onyx processor is the host for one company's rapid-prototyping system, and an SGI 4D/220VGX is the central processor for its cockpit development simulator. There appears to be a migration toward Unix-based platforms, in general, and SGI processors in particular.

Several companies emphasized the need to use the CDS Toolset in a classified environment. For classified programs, this implies that the hosting platforms would usually be limited to those already contained in the classified facility. For this reason, IBM-compatible PCs, or Macintosh computers, were suggested as the best host platforms, because they tend to be the most widely available. Classified processing would prevent the export of data out of the classified environment. For this reason, data files created for classified programs would not be available for re-use outside of the program itself, even if they contain only unclassified information. Additionally, the use of removable media such as floppy disks and compact disks (CDs) would be the preferred choice for data storage.

CONCLUSIONS AND RECOMMENDATIONS

The review was worthwhile for three reasons. First and foremost, it provided a forum for gathering and updating the CCCD-related requirements of industry. These requirements will provide a sound basis for the subsequent prioritization of future CCCD activities. Second, it provided an excellent means to present the current status of the CCCD Program to interested members of the cockpit design community. Third, it offered an opportunity to garner the interest and the support of the cockpit design community. After each session, the industry reviewers stated that they appreciated the chance to review and comment on the evolving products of the CCCD Program, and affirmed that they would welcome continued involvement.

The industry reviewers remarked that the new approach and direction being taken by the CCCD Program was "headed down the right path." Each of the companies had constructive suggestions for enhancements to both the CSDP and the CDS Toolset. The challenge for the program in the near future is to prioritize candidate CDS enhancements, and to focus on those that are most valuable to both industry and government. This approach is leading to the development of a crew-centered cockpit design process and support tools that will assist in formulating the next-generation cockpits or cockpit modifications. The industry review provided a valuable insight into the prioritization and implementation of near-term CSDP and CDS development.

The establishment of Beta Sites for the installation and use of the CSDP and the CDS Toolset is one of the primary goals of the current phase of the CCCD program. Based in part on this review, the CDS Toolset is being developed with a piecewise architecture so that individual tools, or groups of tools, can be used as they become mature. The CCCD Program Office welcomes inquiries from potential users of the process and tools described in this report. Interested industry or government officials can contact the CCCD Program Office concerning the possibility of becoming a CCCD Beta Site.

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APPENDIX A

DESCRIPTION OF THE CREW-CENTERED SYSTEM DESIGN PROCESS

SECTION 1.0: INTRODUCTION AND BACKGROUND

1.1 Introduction

Welcome to the world of **Crew-Centered Cockpit Design.** This guide will familiarize you with the process, procedures, and tools that are in advanced development under the Armstrong Laboratory's Crew-Centered Cockpit Design (CCCD) Program. The CCCD Program seeks to establish a well-organized, thorough and inspectable process for cockpit development, along with an effective set of the needed software and simulation support tools. The physical product of the development to date resides in a self-contained, integrated **Cockpit Design System**, or **CDS**. The CDS, itself, contains a retrievable guide to CCCD's **Crew-Centered System Design Process**, or **CSDP**. (The terms "CCCD Process" and "CSDP" are used interchangeably in this document.) Recently, we enhanced the previously delivered CSDP and CDS, and now seek your suggestions for further improvement. This document is intended for review by cockpit specialists within the aircraft industry and also by System Program Offices (SPOs) and Government Laboratories.

This guide to the CSDP and CDS was prepared to "walk" you through our support system for cockpit development. The CDS represents R&D work that has been underway for several years, and is still in various stages of development. With your help, we will continue to incorporate system-wide enhancements and corrections that are based upon user needs.

The CCCD Process Overview (Figure A-1) depicts crew system design as an interactive (connecting lines) and iterative (cyclical arrows) process. We define the crew-centered cockpit design process as a logical collection of activities and procedures which examine the role, the *functionality*, and the inter-operability of the crew in conjunction with aircraft, avionics, flight control, and other air vehicle systems to achieve mission goals. Therefore, mission requirements, weapon system capabilities, as well as crew capabilities each can dramatically affect the crew system design object (i.e., the cockpit). Inherent in the CCCD Process are many activities that have common roots in past cockpit development work. We understand the need to balance comprehensive requirements with timely performance. Therefore, this process description includes a discussion of design tools which are intended to dramatically reduce the time to complete most of the activities within the CSDP, while also improving product quality by conforming to accepted standards and formats used by aircraft development organizations. In addition, we include in the CDS an "encyclopedia" of technical and management work **activities** that span the entire realm of crew system development. This encyclopedia is accessed directly through one of the CDS software **tools** and includes specific **procedures** that we recommend be used to perform each activity.

To present the attributes of the new CDS, we employ a "walk-through" method in this document. This walk-through assumes that your cockpit design team consists of individuals with backgrounds in all aspects of crew system design such as pilot-vehicle interface, operational flight, human factors, avionics and other subsystem design and systems engineering. We believe that this approach is a straightforward way to illustrate the many facets of the CDS. We have intentionally omitted a technical layout of the CDS hardware and software architecture in order to focus on the content and the envisioned use of the CCCD Process for cockpit development and upgrade programs.

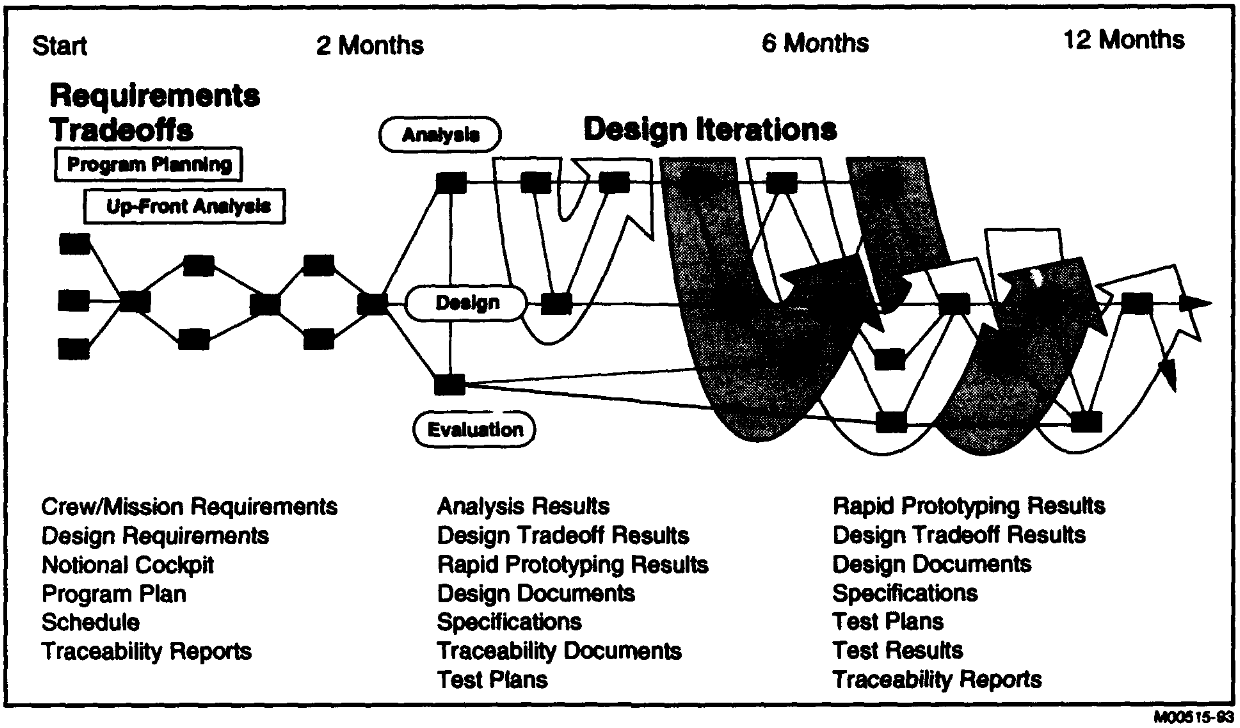


Figure A-1. *CCCD Process Overview*

To further aid the reader, we periodically refer to a more detailed "map" of the CCCD Process, which will be presented later. The map identifies the key cockpit design activities that are included in the overview chart (Figure A-1). The map and this text provide a concise and consistent insight into the essential elements of crew system design. While the CCCD procedures and tools primarily focus on design concepts, the map extends beyond traditional boundaries to include planning, analysis, design, development, and testing of cockpit crew systems. It is important to note that the CCCD Process Map integrates the CCCD Process, procedures, and toolsets to improve the design quality of both the immediate cockpit and the total weapon system. The tools identified in this guide are a manifestation of the currently implemented CCCD Process, and could be replaced with other tools that provide similar support.

1.2 Background

In the past, cockpit design has been somewhat disjointed, with many different organizations, in addition to the crew system design group, vying for the aircrew's interaction with their designs. Often, that was accomplished without a full understanding of: (1) the overall impact of the individual air vehicle subsystem designs on cockpit integration; (2) the established processes imposed by contract requirements or internal policies (e.g., MIL-STDs, Design Documents); or (3) the combined impact of all subsystems upon aircrew workload. More often than not, the cockpit design group was left with the task of fitting many independently designed panels, displays, and controls into the available but limited cockpit volume (i.e., the major focus was on installation, which was necessary but detracted from effective design integration). The resulting cockpits could be mastered only with great difficulty, defied intuition, and failed to meet real-time operating requirements. As a result, it was left up to training and the crew member's ingenuity to make up for limitations in the basic design. The problem was compounded as cockpits were

upgraded, because records for the design decisions and their underlying rationale were not kept, or were not accessible for use during the upgrade. Consequently, cockpit changes could have violated earlier design assumptions. Frequently, cockpit design flaws did not become apparent until flight test. This situation further aggravated cost and schedule if engineering changes were approved; otherwise, the flight crew simply learned to cope with the problems.

Designers soon came to realize that a more formal, structured process was needed to improve cockpit design quality. Recognizing that the Air Force lacked an advanced technology program in the area, the Human Systems Center's Armstrong Laboratory initiated the Cockpit Automation Technology (CAT) program in the mid-1980s. The program was renamed in the late 1980s as Crew-Centered Cockpit Design, to better reflect the aim of the work. Early development was nurtured using contractor teams of aircraft manufacturers, avionics suppliers, and human factors specialists all contributing to the formation of good cockpit design principles, with the pilot/crew aspect of design integration playing a prominent role. Five aircraft development prime contractors made contributions to the program's current technical state. To date, the CCCD Program has produced an extensively documented but untested first prototype process for cockpit design. In addition, this document speaks to a future computer design support system which will incorporate much of what we have learned during this contract and what the industry reviewers will contribute. Both phases are introduced in this guide. For further information, a description of the evolution of the CDS toolset is provided in the appendix to this document.

Both aspects, the **process** and the **toolset**, are now being applied in a series of field demonstration applications to a variety of typical cockpit upgrades and developments. To help advance and mature this technology, the advice of users in the crew system design community is now sought so that the CCCD Process and the CDS will contain a sufficient depth of knowledge, along with the complete and detailed procedures for applying the technology in a usable form for industry environments.

Advancing avionics now present to designers the opportunity to consolidate the interactions among multiple onboard subsystems into a consistent, integrated cockpit environment. These gains, coupled with lessons learned from recent cockpit developments, have helped the cockpit design community to better adhere to the design practices that are established in MIL-H-46855. Notably, designers of recent military aircraft cockpits attempted to comply with the specification and used some available (custom) tools to produce integrated cockpit systems. Industry designers achieved modest success at formulating integrated cockpits. However, not all recommended activities were followed, and the necessary depth of analysis, design, and evaluation was not performed to produce crew-centered systems or to trace the cockpit design characteristics to specific requirements. In all fairness, industry had little or no access to a documented, verified process and few tools with which to execute any process. Moreover, time and schedule factors precluded the full, iterative use of a crew-centered cockpit design approach, denying the resulting advantage that CCCD offers. Cost and schedule constraints are the realities that will continue to dominate what can be achieved in crew system development. The CCCD Process and tools aim to help industry designers work more effectively within those constraints.

With the change in emphasis of aircraft systems and cockpit design activities came the challenge to interact with many different organizations to coordinate a consistent, intuitive, and logical cockpit. Integrated avionics now allow cockpit functions to be grouped by tasks and not by individual systems. For example, mission avionics systems can gather target data from various sensors, and are able to fuse the information into symbols on a single display that discloses the track's identity and the presence of radar or infrared radiation. If designers levy duplicate information requirements throughout the cockpit, forcing the pilot/crew to consult several displays for dedicated bits of information, crew members will soon be overwhelmed with data, inhibiting their ability to extract the needed information. That has been a recognized problem since the emergence of digital avionics technology in the mid-to-late 1970s. Because the designers of

individual subsystems are concerned mainly with their own systems, and only secondarily with their impact on the total cockpit environment, cockpit designers must translate total crew/mission requirements into finite, streamlined design features. Further, they must understand how one system affects another and agree on a form that complies with the existing aircraft design specification process. This is the challenge for today's cockpit designers: to communicate, coordinate, and design cockpit systems that function in support of air crews performing essential missions.

From a system design perspective, the Air Force acquisition community is moving to a new Integrated Weapon System Management (IWSM) philosophy. This philosophy relies on Integrated Product Development (IPD), with teams representing all of the applicable design disciplines. Based on tenets from Total Quality Management, the new CSDP approach also borrows from the methods and framework of concurrent engineering and IPD. For years, industry has employed a similar team approach for cockpit development, partly because the cockpit is the place where many of the air vehicle subsystems "come together" during the process of system integration. That cockpit integration process can now be further advanced -- and hopefully implemented for IWSM in major system development -- by the structured and inspectable CCCD Process and its CDS family of design support tools, once they are proven.

Giving further importance to a human-centered design approach is the idea of Human System Integration, which is now mandated under the DOD 5000-series of directives and instructions that guide the major defense system acquisition programs.

The challenge for the CCCD Program is to mature the process, procedures and tools that are needed to sustain future mandates for proper crew system design, within the context of global system design to support mission objectives. "Proper" cockpit design means to provide: 1) a comprehensive set of understandable (analysis, design, and evaluation) activities that are necessary and sufficient to produce a good cockpit design; 2) a fully understood tradeoff rationale leading to the design; and 3) an understanding of why the design is good. Due to the fact that each of these is performed increasingly earlier in the weapon system design cycle (to produce the desired effect upon the entire system), we are further challenged to apply the process, procedures and tools in a quick, efficient and verifiable manner.

The advantage of having a formal, structured process for cockpit design (and effective tools for implementation) may be even more important as the defense industry is "downsized," to augment the remaining workforce after the industry stabilizes. The new CCCD Process and its CDS Toolset can have a secondary value deriving from their potential use in training new crew system designers, as some experienced designers approach retirement.

Our crew-centered design approach provides the opportunity for making those improvements. By examining the substance of the CCCD Process, and by deriving measurable "attributes" during its execution, the products of the CCCD Program can be molded into a form that all can use. Although the CDS strives to provide a standard, repeatable crew system design process, it has yet to be demonstrated, validated, or enhanced. That is the purpose and the promise of the current phase of the CCCD Program.

The CCCD Process is merely a reference model that can be tailored and modified as needed to streamline your particular cockpit development. Additionally, it can be used in a variety of ways and modified as needed through careful program planning and scheduling. Your constructive suggestions for refining and extending the present technical status of the CDS and the CSDP will be genuinely valued inputs toward achieving that promise.

SECTION 2.0: PROCESS OVERVIEW

2.1 Organization

The CCCD Process organizes all activities necessary for cockpit design into five major functional categories:

- Program Planning
- Up-Front Analysis
- Crew System Analysis
- Crew System Design
- Crew System Evaluation

These activities are performed in parallel and iteratively to improve the quality of the design product (i.e., the cockpit). In addition, the CDS includes specific procedures that guide the performance of each activity, and also has tools that facilitate the validation of the cockpit. Finally, the CDS supports the generation of program deliverables (e.g., specifications and contract CDRL data) which can be implemented immediately using the CDS and delivered to the customer. These deliverables specify both the actual design and explain why the design looks as it does.

The CSDP's distinct (and interdependent) functional categories are purposely organized into two phases. The first phase allows you to perform functions of "Program Planning and Up-Front Analysis" with guidance and support from specified tools and procedures. These two CSDP categories were omitted from earlier versions of the CSDP. They are done simultaneously so you can plan the crew system project as you develop an understanding of its requirements. This phase ensures that your plans meet the crew's requirements to perform the mission. Translating the global mission requirements for the weapon system into crew system requirements and then into engineering objectives is an important first step within the CSDP.

In the second phase of activity, you perform an organized set of crew system analysis, design, and evaluation activities, both sequentially and in parallel. The CDS contains software tools and procedures to support all aspects of this work. Importantly, the CDS is self-contained and small enough to remain under the direct control of the cockpit development team, which could simplify or eliminate the need for interfacing with another support department. The elements of crew protection (e.g., life support equipment, escape systems, and environmental control) are critical to cockpit development projects, especially for combat systems that employ ejection seats or escape capsules; thus, the CSDP provides for their consideration. Due to the fact that escape and life support technologies are currently being worked in separate advanced projects within the DoD, the CDS Process calls for an analytical look at these systems as a means of revealing the important cockpit integration factors, but does not delve into further detail.

As illustrated in the maps and their accompanying CSDP tools and procedures that follow, many of the activities within the second phase need to be performed interactively with other activities and iteratively within the development cycle, in order for the process to truly improve quality. Each step of the way, the CDS recommends the appropriate action with respect to the plan you have developed, through text and graphic aids. In addition, the timing of all activities and products adhere to <u>your</u> schedule. Tools and procedures are also being developed that will allow for quick delivery of intermediate and final products.

The key to using the CCCD procedures and tools, and also to understanding the timing of activities, resides in the ability to "see" how all of the parts fit together. In order to unlock these aspects, we developed a "map" of the CCCD Process and a narrative guide that explains the map.

2.2 CCCD Process Map

The CCCD Process Map (referred to below as the "Map") depicts the "mainline" activities performed when developing a cockpit design. Of course, there are many other potential activities that may need to be performed, depending upon the objectives of your particular program. Within the Map, we embedded "avenues of access" for those events, at appropriate stages.

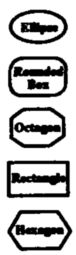
The Map is a computer-interactive way to guide you along the development of your cockpit, throughout the life cycle of your program. As such, it provides you and your design team with the ability to understand the issues surrounding immediate tasks, and includes the perspective to see how that activity fits within the entire design approach. The Map comes in two forms, a "micro look," which shows procedural detail of an activity, and a "macro look," which shows an activity in relation to all others. Macro maps contain useful information about both input/output requirements and activity status. Together, micro and macro views of the CCCD Process Map offer guidance about the CSDP activity order, the scheduling, the product technical development, and the overall timing of program activities.

At first, the Map may deceive you into thinking that the process is too large to be accomplished. Although it shows a considerable number of activities, the provision of procedures for performing the individual CSDP activities, and the availability of the CDS tools, will allow you to accomplish more activities with little or no increase in time or cost, when compared to past cockpit development programs. This is due in part to the elimination of input/output formatting problems for much of the design data, which can be automated within the CDS. When fully developed and proven in applications, the CDS should enable design teams to produce a high quality of cockpit design, while tracing requirements flowdown and design decisions throughout development.

Of the many activities that need to take place, some must be re-accomplished on an iterative basis. This is necessary, in the sense that one acquires greater knowledge with each pass (adding value to later dependent activities). It is also desired, in the sense that all final products are made better by a continual cycle of inspection, analysis, and change. The CCCD Process relies upon the design iteration (through several cycles of the prototyping, analysis, and simulation in support of tradeoff design activities). The process also relies upon activity interaction (between analysis, design and evaluation activities) to ensure quality during the process.

The overview CCCD Process Map (Figure A-2) illustrates the interactions among activities, and invokes the iterative nature of the cockpit design process. In addition, the map shows both sequential and parallel activities during the development cycle. In this way, the CCCD Process reflects and builds upon current industry practices. Within the Map are the five functional categories that were listed previously, Program Planning, Up-Front Analysis, Crew System Analysis, Crew System Design, and Crew System Evaluation). These categories are shape coded as follows:

Legend:



Program Planning Activities

Up-Front Analysis Activities

Crew System Analysis Activities

Crew System Design Activities

Crew System Evaluation Activities

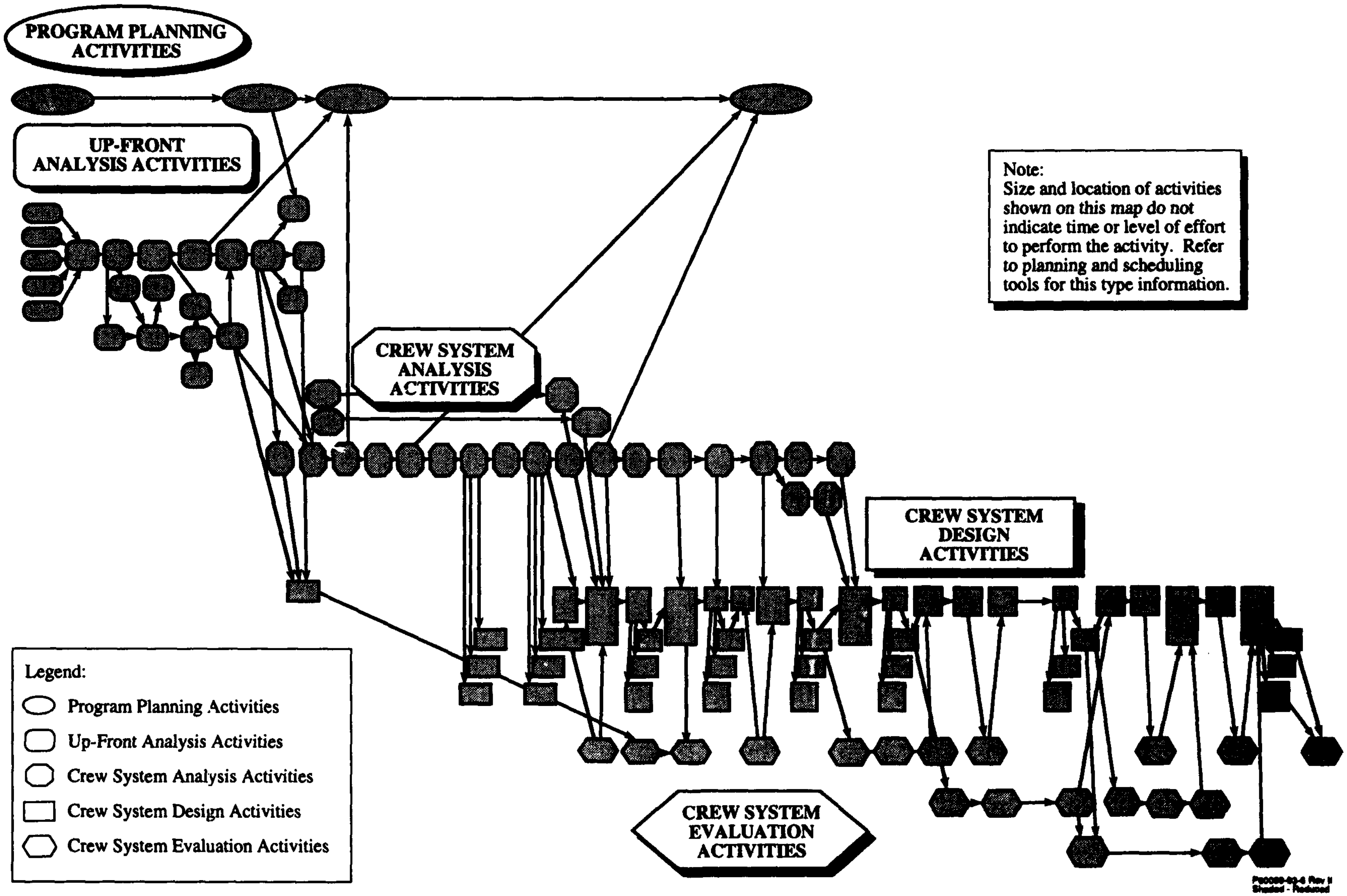


Figure A-2. Overview CCCD Process Map

In addition to the shapes, you will notice that in the detailed process maps (Figures A-5 to A-8), a certain number of activities are shaded darker than the others. This notation is used to identify critically important documentation prepared during the process. Many of these reports and documents are common CDRL requirements, while others are significant internal communications. A major aim of the CCCD Process, Procedures and Tools is to support the development of required documentation.

The Map is a kind of process flow chart, where time generally "flows" toward the right side of the chart (reflecting the availability of interim results as the design becomes refined over time). As will be seen later when **parts** of the chart are detailed, the actual development of the design (the second phase noted above, distinct from the Up-Front Analysis and Program Planning phases) is represented by separate "threads" for Analysis, Design, and Evaluation work, each of which is stacked vertically and shown as a horizontal set of activities on the chart.

The Map is also implemented as software within the CDS and is intended to be one of the on-line planning tools to help crew system managers and engineers make informed choices about the development's progress.

2.2.1 Discussion of Map Phases

Throughout the Map, you may notice our attempt to force tradeoffs, results, and conclusions. We believe that decisions should be made based on crew and mission requirements, and not primarily from single interest or "group think" sources. The CCCD ideology provides an inherent way to trace your design decisions, using both qualitative and quantitative results, in a manner that promotes both efficiency and design effectiveness while still utilizing operator opinion. The Map phases discussed below follow the two-phased structure noted above.

2.2.1.1 First Phase

The initial phase of the Map assists in performing two critical categories of activities prior to developing your cockpit:

- Program Planning (ellipses), in which the necessary activities, schedule, and cost estimates are defined, to link the cockpit design to requirements; and,

- Up-Front Analysis (rounded boxes), in which the cockpit requirements are derived from upper-tier requirements.

Other products from this section yield initial information for other activities (such as notional cockpit design, system drivers, mission profile data, etc.). Each individual activity is discussed within its respective functional category. The key output products from activities within the first phase are a Design Requirements Document, the Initial Crew System Specification, and a Program Plan.

2.2.1.2 Second Phase

The final phase of the Map is designed to assist you in performing three critical categories of cockpit design activity and two value-added improvements to developing the cockpit as follows:

- Crew System Analysis;

- Crew System Design; and,
- Crew System Evaluation.

Value-added improvements are represented on the Map by the interactions among the activities (shown by arrows) and by design iterations (shown by repetition of design activities), which are performed as many times as possible within your timetable. The highlights for each of the three types of activity within the second phase are summarized below, in turn.

The Crew System Analysis section (octagons) of the Map represents two vital functions in the development of your cockpit:

- Derivation and verification of crew requirements; and,
- Definition of the operating limits for crew and system.

The principal output products from the Crew System Analysis activities are the Mission Profile, Mission Scenario, Functional Flow, Action/Information Requirements, Function Allocation Trade, Task Timeline, Task Workload Analysis, and updates of the Cockpit System Specification, and the Cockpit Traceability Report. The outputs can be in paper or electronic form, and can include text files, charts, graphics, and computer data files.

The Crew System Design section (rectangles) represents two essential functions in the design of your cockpit:

- Integration of all information about your system (for defining the cockpit design); and,
- Production of the system documentation of that design.

The principal output products from the Crew System Design activities include the Cockpit Mechanization Document, updates to the Cockpit System Specification, and the Cockpit Traceability Report. Again, the outputs can be in electronic form or in hard copy.

The Crew System Evaluation section (hexagons) will help guide you in performing what is perhaps the most important function associated with your cockpit design: cockpit design verification. In this section, your design is verified in terms of its crew/mission requirements, acceptance, implementation, and intuitive appeal. In addition to evidencing its "market appeal," data is developed to convince your customer, SPO and/or the user commands that your design meets or exceeds requirements.

The principal output products from the Crew System Evaluation activities include the Dynamic Simulation Plan, Mockup Evaluation Plan and Report, Rapid Prototyping Evaluation Plans and Reports, Part-Task Simulation Plans and Reports, Full Mission Simulation Test Plans and Reports, Flight Test Plan, and individual Flight Test Plans and Reports.

All of these output products (in both phases) take on added importance because they are the observable marks of your technical progress. To the extent that they can be easily retrieved and inspected, they can be used in the sustaining engineering phase of the system life cycle for managing changes. During this later phase, it is unlikely that personnel from the original cockpit design team will be available for guiding these changes.

The Map also shows how and when the interaction of activities needs to occur in order to better perform all activities. In addition to the lines of communication shown, each procedure promotes the use of information from other products. The final feature of the Map is its ability to

show the nature and timing of design iteration. The key to improving cockpit design quality resides in one's ability to redesign, and effectively use all available information from analysis, design, and evaluation. When fully exploited, the combined information produced from these activities can have a profound effect on your design. The keys to help you gain that advantage are the availability of the information (assured by performing the CSDP using the recommended procedures) and the ability to quickly access the data when needed (assured by the use of the CDS data management software).

SECTION 3.0: CDS IMPLEMENTATION

3.1 CDS Implementation

The CCCD Process is represented in software that runs on the CDS. The implementation is in the form of a "Guidebook" that is analogous to the CCCD Process Map in this document, but that also provides all the detailed explanations, experiences, guidelines, and requirements needed to perform all phases of crew system design.

An earlier version of the CCCD Process was documented in several cumbersome paper reports, separately tailored for each of the four classic phases of weapon system acquisition. That was useful as a reference and to place bounds on the actual CCCD Process, but clearly the hard copy representation was not streamlined for implementation. Taking the next step toward that implementation, and to permit a better understanding of the crew-centered approach, we "repackaged" the hard copy design process to the simpler form described herein. In the sections to follow, the new CCCD Process is pictorially and textually presented in a form that will aid the designer's appreciation of the interactions among the many CSDP activities. The new crew-centered design process is, itself, implemented as interactive software, which allows the crew system designer to: (1) inquire about an activity; (2) directly perform an activity; and (3) plan and manage single or multiple sets of activities through a collection of (prompted) procedures and tools.

3.1.1 Activities

An activity is the lowest level of coordinated effort needed to gain a specific understanding of an event, or a series of events. For example, this definition applies to information and control requirements analysis, to the design of a particular display format, such as a Tactical Situation Display format, and to the preparation of a test plan for the initial part-task simulation evaluation. In each case, there are individual CSDP procedures that should be accomplished to conclude the activity with an output product, such as the principal outputs identified above.

3.1.2 Procedures

A procedure is a set of individual actions that, collectively, produces a repeatable outcome. We prescribe standardized sets of valid actions for each activity, which can be implemented alone or through the use of an integrated toolset such as what exists within the CDS. Simply stated, we recommend and describe (in a sequential, detailed electronic format on the CDS) which analytical or design or evaluative factors to apply; which activities or database inputs are necessary prior to action; what actions are required; how to derive conclusions and results from each action; and useful output in terms of products that can "stand alone" or support other activities as inputs. The product orientation for the CSDP activities and procedures serves the four purposes: (1) it clarifies the technical tasking; (2) it supports management by providing visibility into the progress of the design; (3) it directly provides a means to record the technical rationale and traceability of the cockpit design; and (4) it permits the potential re-use of CSDP data by other Product Development Teams.

3.1.3 Tools

A tool is an instrument which, under the control of a skilled user, can aid in performing work activities. The CDS contains several software tools that were specifically made to support most of the activities that are shown on the Map. When applied to an activity, the user benefits most from cost and schedule savings. Once fully developed and tested, the CDS tools will be a convenient way to carry out the activities specified by the CCCD Process. It is important to note that the CDS is not intended to replace the designer, or to make a novice designer into a skilled design professional. The CDS cannot supply the creativity or ability of an individual to perform this specialized work. As a design support system, however, it can provide guidance to the cockpit design team, markedly improve communications within the integrated product team, help "prove out" the design at an earlier stage in system development (i.e., promote efficiency), and help to attain a total quality design product from both crew and mission standpoints.

3.2 Management of CDS

The CDS is controlled through a software interface tool known as the Design Traceability Manager, or DTM. DTM provides a standard interface for all other tools within the CDS. It supports project management and scheduling, guides the design team in the use of CDS, records day-to-day activities, maintains design and decision traceability, and accommodates multiple users like those in an Integrated Product Development environment. These are just examples of the depth behind this management system. In essence, the DTM can be viewed as a software "executive" for the CDS.

A simple, consistent, and flexible windowed environment is at the core of the DTM. It allows *straightforward management* of many of the details within your responsibility. In a typical work session, you use a mouse to select one of the following five functional areas of the "top-level" page (Figure A-3):

- **Main Menu:** Project Management Functions, DTM Utilities, and Tool Execution
- **Current Status:** Current Status of User, Project Information
- **Interactive Data Entry Forms:** Product Traceability Functions, Lessons Learned
- **Navigation Buttons:** Individual and Multiple CSDP Activity Control
- **Current Activity:** Work Space of Activities and Procedures (Scrolling)

Through DTM, you can learn who is responsible for an activity, how to accomplish the activity, what information or database to use, when your results will be needed, what type of results are needed, and where they will be used within the project. In that way, you have visibility into how your work products fit into the overall scheme of development. You can trace past activities, log new ones into the system, and call up a CCCD Process Map that is specifically tailored to your project, to find out more about individual pieces or to determine progress within the process.

At this point, it is useful to note that the CCCD Process is not a rigid way to perform work that will be levied on you. Rather, it is a reference model that can be tailored and modified as needed to streamline your development. Because it resides within a computer implementation, it can be used in a variety of ways and modified as needed (by those having such authorization privileges).

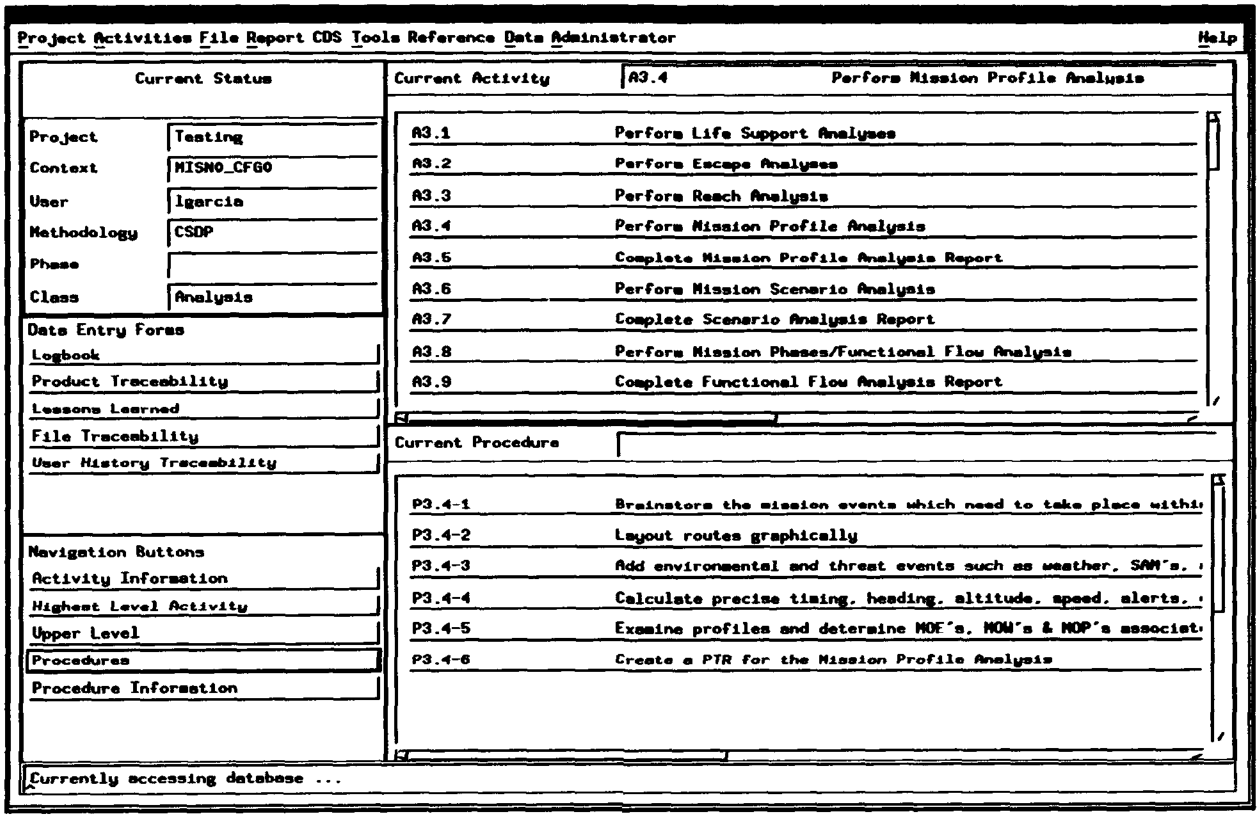


Figure A-3. Example DTM Page

The crew systems engineer can select specific sections of the process to investigate. In an interactive "session" with DTM, the user can progress through finer levels of the process until the desired information is located. This **indentured** presentation of topics permits rapid navigation to a precise area of interest.

Once an engineer selects an avenue of investigation, the DTM guide reveals formal proceduralized activities, likely approaches, lessons learned, and pertinent experiences. Design constraints and interdependencies will also be displayed. This procedure page (Figure A-4) contains summary information that will be vital to the swift completion of the referenced activity. We also provide a detailed method for accomplishing each activity. Further, we recognize that there may be other ways of performing the same work. Our procedures merely reflect proven methods to complete all activities. The example procedure page is shown for the activity of "Perform Functional Flow Analysis." This information includes: (1) the functional category of the activity, i.e., Up-Front Analysis, Program Planning, Analysis, Design, or Evaluation; (2) the actions required to perform the activity; and (3) detailed sub-actions that describe predecessor activities, individual procedures, management considerations, output requirements, database references, and recommended tools to perform the work.

3.3 CDS Tools

In order for the design team to accomplish its gamut of activities, such as performing needed analyses, formulating and deciding among tradeoffs, producing data and physical products,

Perform Functional Flow Analysis

Description: Functional Flow Analysis

Functional Flow Analysis is used to establish the flow of critical mission segments and to provide a vehicle for breaking down the critical mission events to the task level. The analysis uses critical mission segment Level I, II and III block diagrams as a means for producing the functional flows. The following describes the content associated with each of the block diagram levels.

Level I block diagrams will be used to develop the overall flow of the composite mission from start to finish. The mission will be broken down to the level of critical mission segments based on a specific or composite mission. Mission phases will define each mission segment to be considered for subsequent analysis (e.g., ingress, target area operations, egress, etc.).

The purpose of the Level II block diagrams is to establish the flow of the mission at the gross task level and will be directly based on the critical mission segments defined within the Level I block diagrams. Level II block diagrams define the major functional tasks to be performed within each of the specified critical mission segments.

The Level III block diagrams will be developed by further detailing the Level II block diagrams and performing an initial system/pilot task allocation based on a preliminary assessment of the repeatability of the task and the required accuracy of performance. The Level III block diagrams define the critical mission segments to the level of the operator task.

Predecessor(s):

In order to proceed with the Functional Flow Analysis you will need to have some details about the order of the mission events and the type of events which need to take place. A mission scenario and mission profile will supply you with this type of information.

Procedure(s):

1) Break down the mission(s) into distinct phases of operation based upon previous, similar missions and the introduction of new technologies and/or tactics (block I diagrams)

- Look at the logical flow of events contained in the mission profile and scenario and construct a functional segment breakout of each mission. This typically is terms such as pre-flight, takeoff, enroute cruise, etc.
- Assess similar type mission functional flows from the mission functional flow database to verify your terminology and placement of mission segments.
- Create a numbering system of the block diagram entries in order to provide traceability between the lower and higher level functions and between functions at the same level. This same numbering system should be used throughout all other crew system analysis activities for consistency purposes.

Typically the numbering system is 1.0 for pre-flight segment, 2.0 for takeoff segment, 3.0 for enroute cruise segment, etc. Then each segment will be broken down further for each level of information. An example might be 1.1 is the pre-flight checklist accomplishment and 1.1.1 is check brake pressure, which is the first item of the pre-flight check list. Presentation of the mission data in the block level diagram (graphic) format permits the user to grasp the mission at each of the levels of detail available, and to understand the task requirements associated with each mission phase. It is typically more effective than a textual tabular format of sequential indentured tasks.

- Lay out the sequential segments for the mission(s) being analyzed

2) Provide a written description of the events contained within each phase

- Put together a written account of what major segments will be taking place during each mission. Any insight into the particular cockpit requirements of those phases should be documented as well for future use.

3) Break down distinct mission phases into functional activities performed by each crew member for each segment (block II diagram)

- Look at the logical flow of events contained in the block I diagram of the mission and decompose a functional activity breakout of each segment. This typically is terms such as: perform fence check, update navigation system, contact with tanker, etc.
- Assess similar type mission functional flows from the mission functional flow database to verify your terminology and placement of functional activities.
- Continue with your numbering system of the block diagram entries.
- Lay out the sequential functions within each segment for the mission(s) being analyzed

4) Provide a written description of the events contained within each functional activity

- Put together a written account of what major functional activities will be taking place during each mission segment. Any insight into the particular cockpit requirements for each functional activity should be documented as well for future use.

5) Break down each functional event into distinct tasks performed in order to complete the functional flow breakdown to its lowest level (block III diagrams)

- Look at the logical flow of events contained in the block II diagrams of the mission and decompose a distinct task breakout of each functional activity. This typically is terms such as: acquire target visually, fire AIM-9L, observe target destroyed, etc. This can be as many tasks or sub tasks as necessary to decompose the task down to a single action (even when more than one sensory condition applies), (block III or more diagram)
- Assess similar type mission functional flows from the mission functional flow database to verify your terminology and placement of mission tasks.
- Continue with your numbering system of the block diagram entries.
- Lay out the sequential functions within each segment for the mission(s) being analyzed

Product(s):

Upon concluding your function flow breakout, you will have the documentation for developing all levels of flow throughout the mission. This data will be used to graphically produce the mission flows when you produce a report.

Each of the Level III Blocks of information will be used to provide the basis for the action/information requirements analysis and the task timeline and task/workload analyses.

Successor(s):

The information from this analysis will be gathered for a report in which the mission will be portrayed in a graphical flow format. The information will also be used to perform action/information requirements analysis and the task timeline and task/workload analyses.

Recommended Tool(s):

The Functional Flow Analysis tool (that is currently Concept Mapper but Design 3.0 is also a good choice - more flexible) should be used to develop the information. The lowest level block textual data will also become the basis for a subsequent analyses and therefore should be entered into TMT as is, including the numbering system.

Recommended Reference Database(s):

The yet to be developed Functional Flow database will need to be accessed to look at previously accomplished functional flows of similar mission and crew size requirements.

Figure A-4. Example DTM Procedure Page

and integrating (electronically and practically) the large amount of cockpit-related information within the applications project, we are developing tools and databases to support these necessary functions.

Most CDS activities and products use a database or associated software tool to expedite task accomplishment. We consider an expedited task to be one where the engineer considers multiple information sources, uses design data from validated concepts proven in related applications, and meets time/schedule deadlines to produce an effective and operable cockpit design.

3.4 CDS Usage

To fully appreciate the value of the CCCD Process and the CDS Process Map, the following material will step you through a generic cockpit design example. It was prepared in the form of a "users guide" to promote understanding within the cockpit design community. Our intent is for you to focus on <u>process requirements</u> as you critique the material.

Throughout this description, we identify the databases and tool attributes that are required to accomplish the activities and to produce observable products. Currently, some of these tools are prototypes, some are beginning development, while others are being derived from design requirements. An initial set of CCCD tools from another earlier development contract (CAT) was re-hosted and evaluated, leading to the present status of the CDS. We include below a description of the present and proposed enhanced CDS toolset to illustrate the premise by which the CCCD Process is being implemented. As you review this guide, please keep in mind that we need your expertise to identify any appropriate tool modifications and new requirements that will enhance the CCCD Process, procedures, and tools so that they can meet your needs as crew system developers. As noted earlier, a historical development of the CDS toolset, as it evolved and where it is heading, is described in the appendix to this document.

As a notational convenience, we represent below the *updates* and *refinements* to earlier design information during the application of the CCCD Process in *italics*, the use of specific CDS software **tools** in **bold** print, and the specific observable <u>output products</u> from CSDP activities are <u>underlined</u>.

Each of the activities marked with bullets (•) in the following paragraphs coincide with those comparable activities on the accompanying CCCD Process Map.

START OF PROGRAM

You begin by addressing USAF requirements documents that are typically used to initiate a new aircraft program. Similar requirements documents are used for cockpit modification programs, both during the development and the sustaining engineering program phases. These documents include a System Operational Requirements Document (SORD), Statement Of Need (SON), initial Prime Item Development Specification (PIDS), and Threat Assessment Report (TAR). Often, these formal requirements documents are made available to the industry Program Manager by the SPO as an addendum to the aircraft development contract.

PROGRAM PLANNING AND UP-FRONT ANALYSIS

The following detailed map (Figure A-5) of Program Planning and Up-Front Analysis will help guide you through the next two sections of this document. The activities are closely dependent upon each other to determine the direction of your cockpit.

- Examine SORD
- Examine SON
- Examine PIDS
- Examine TAR
- Identify Known Similar Cockpits and Technology

As always, the first step is to examine Government-furnished documentation to understand what direction to take the cockpit. The documents will already have been summarized (possibly by someone in the group) to include the key design elements for the cockpit system. This information is entered into the program documentation database within the CDS. All members of the cockpit integrated product team should glean what they can from the stated requirements, and contrast the system demands against background information that they bring from their individual areas of expertise. The design team has access to several information sources within the CDS. Several databases such as cockpit configurations, lessons-learned, projected cockpit technology, mission/task analysis, and cockpit-related military standards and specifications are also planned for implementation. Ideally, all project-specific information files would reside within a relational database program of Database Management Software (DBMS) that is accessible through the CDS' **Design Traceability Manager (DTM)**. Of course, each new development will have other information that will not reside in the CDS at the outset of the project and will have to be assembled. The crew system design manager then initiates the cockpit project through the **DTM**, creating a place for future electronic documents.

- Evaluate Results of System Requirements Documentation

The next step is to use an "up front" analysis technique to help the team translate system requirements to cockpit requirements, and then to engineering design objectives. The DBMS in CDS readies each document for critical on-line examination. From there, you pare down the information into priority *crew requirements* and *mission requirements*, which can be traded against each other. This is done to determine which requirements should have the highest weighting to assist you in deciding the direction of your cockpit design approach. The lessons-learned database also provides knowledge from previous programs to assist you in prioritizing the requirements. However, as in current practice, it will be a judgment, based upon the experience of your design team and the project leaders, which ultimately guides your approach.

- Determine System Drivers
- Define Problem Statement
- Define Cockpit Philosophy

The final, prioritized requirements will be "downloaded" to the **Design Tradeoff Tool**, which permits the team to both qualitatively and quantitatively evaluate requirements relative to each other and to the mission of the aircraft. The resulting information will allow you to produce two key items. First, you identify a set of system "drivers" for your cockpit, which cover factors

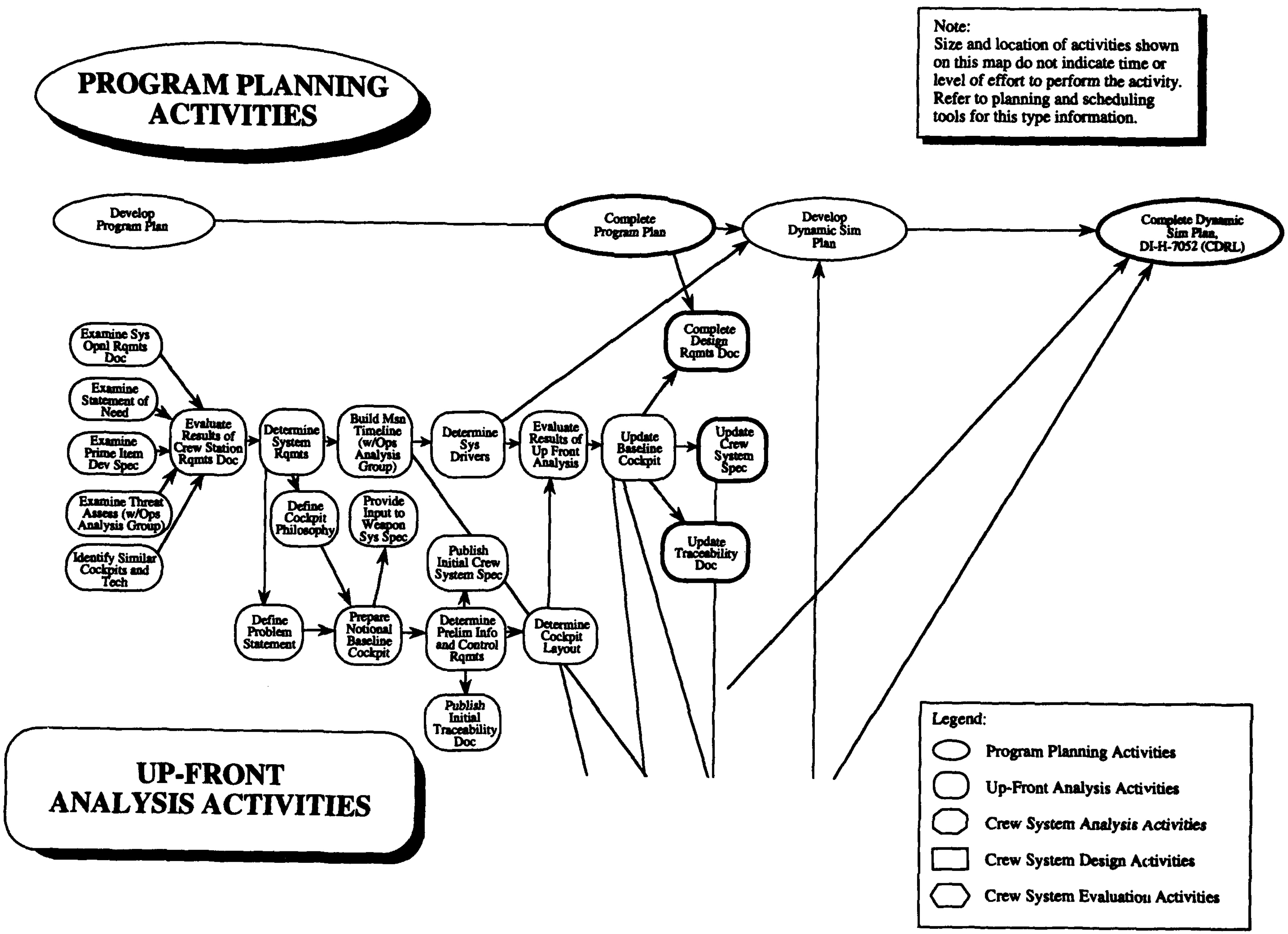


Figure A-5. Process Map - Program Planning and Up-Front Analysis Activities

such as capability, range, performance, and identify the necessary cockpit functions. Second, you then use this information to develop a problem statement about what the cockpit should accomplish, and a philosophy of how your cockpit should be designed. These products become the basis for both notional and actual cockpit designs.

- Build Mission Timeline

Concurrently, you also build a mission timeline, or a family of timelines, to determine what crew actions within the cockpit are required and the time available to accomplish the mission. This is one way to incorporate pilot/crew considerations into a crew-centered design approach as advocated by the CCCD Program. Typically, this work would initially be performed by an Operations Analysis Group using computer simulation models such as TAC BRAWLER or SUPPRESSOR. These digital simulations represent the approximate mission, threats, and aircraft factors that can and should influence your cockpit operation. Usually, these simulations do not model the crew actions to the same extent that they represent the physical systems. Therefore, the team performs an analysis using a **Mission Decomposition Tool,** which is included in the CDS. With this **MDTOOL**, you can examine the flow of the mission from a crew perspective. This will allow you to try out several approaches to accomplish the mission, and then examine how your *derived* requirements compare with mission drivers.

- Determine System Drivers

- Prepare Notional Baseline Cockpit

Armed with information about how our requirements fit the mission, you can now work two critical aspects of cockpit analysis:

- Determine cockpit design drivers in terms of technology, mission, tactics, human performance attributes, and crew requirements

- Prepare a notional baseline cockpit design (including graphics and text)

These activities will be accomplished with support from a **Cockpit Product Tool** which allows you to collect information, while creating text and graphical documents about your cockpit design approach. This material can be used within your company and throughout the SPO. The specific, tailored product applications are discussed throughout this document.

- Provide Input to Weapon System Specification

Once a notional cockpit is available, you can begin to have a dramatic influence on the aircraft itself. You will need to assemble your *input* for the Weapon System Specification (WSS), based upon our notional cockpit. Again, our **Cockpit Product Tool** will allow us to take the derived requirements and formulate an input to the WSS which will be in a correct and usable format. The tool simply asks you to review and clarify each requirement (or point out any deficiencies from associated WSS inputs) before consolidating the final inputs to the WSS. By "staking your claim," other system and subsystem designers now know that the cockpit has up-front requirements, which must be represented in each of their subsystems.

- Determine Preliminary Information and Control Requirements

- Develop Initial Crew System Specification

Another critical activity is that of the initial information and control requirements analysis. In this analysis, you examine mission and crew requirements to learn what the crew needs to look

at and control within the cockpit, for each specific task to be performed in the design mission. Our **Information and Control Requirements Analysis Tool** assists you in creating these requirements. The outcome of this analysis then flows into the **Cockpit Product Tool**, to allow the team to prepare an initial Cockpit System Specification (CSS). In this specification, you begin to detail the elements of our cockpit from a requirements standpoint, based upon an initial Action/ Information Requirements Analysis. Again, this "claim" deepens the understanding of your crew system requirements by all the air vehicle system and subsystem designers.

- Determine Cockpit Layout

While the above analyses provide requirements for the rest of the system, they also help to formulate the cockpit layout. You prepare the layout using CDS's **Crew Station Geometry Tool**, which transforms analysis results and the notional cockpit into a representative, dimensionalized physical cockpit layout, which begins to approach the desired individual control and display design elements of the cockpit. Our database of past cockpit layouts assists you in making recommendations for the cockpit's geometry, layout, and dimensions.

- Evaluate Results of Up-Front Analysis

The results of these analyses and preliminary designs will need to be re-examined through the **Design Tradeoff Tool** to ensure that initial tradeoffs remain aligned with any evolving requirements. The outcome of this tradeoff analysis allows you to change the crew system requirements or the physical layout of the cockpit. In turn, this leads to an update of the Cockpit System Specification (CSS) and an improved set of requirements.

- Complete Design Requirements Document

Upon conclusion of the Up-Front Analysis, you will need to formally produce a Design Requirements Document (DRD), which contains your philosophy of cockpit development and summarizes the results of the analyses and tradeoff studies performed to date. This DRD becomes the basis by which you further *refine* the cockpit design via CCCD analysis, design, and evaluation activities.

- Publish Initial Traceability Report

Throughout the Up-Front Analysis activities, you should trace and document (at least once) the desired cockpit requirements. Currently, **DTM** electronically handles the associated traceability files, which your engineers have updated each step of the way, recording how and why each decision was made. These files can be reviewed independently, or consolidated with tradeoff decisions and cockpit descriptions, to produce an initial Traceability Document.

GENERAL

While the Up-Front Analysis and tradeoffs take place, the team gains an in-depth assessment of the requirements for both crew and mission. With this new insight, you will also be able to compose a Program Plan that implements the remainder of the cockpit development program. You accomplish this with support from a **Program Planning/Scheduling Tool (PPST)**. This tool contains a database of planning and resource information for access by activities throughout the program.

PROGRAM PLANNING

To plan an effective cockpit development program, you need to know a great deal about the specific crew and mission requirements, be able to accurately estimate the design team's level and balance of manpower and experience, and be able to prepare a realistic budget. Having already accomplished Up-Front Analysis and tradeoff functions, you need to develop a sense of what is needed for the remainder of the program. Again, background information contained in CDS Databases can provide examples of scheduling, requirements, activities, and similar cockpit system developments. These databases assist you in planning, but the experience within your team will likely dictate who you assign to lead and perform the balance of activities within the program. The **Program Planning/Scheduling Tool** will guide your development of plans and schedules.

Two main functions of the **Program Planning/Scheduling Tool** are the selection and scheduling of activities. Both need to be performed concurrently, to allow for a coherent plan which meets program cost, schedule, and quality objectives.

- Develop Program Plan

Within the program plan, the order and extent of CCCD Process activities depend upon how well the crew and mission requirements are developed. The planning function helps you to reflect the current requirements and cost during the major technical part (i.e., second phase) of the CCCD Process. This function also delves into other support areas, such as Integrated Logistics Support (ILS) activities, helping you to decide how to best allocate the available time. Again, decisions of this type are only as good as the experience of the team and your understanding of requirements. In conjunction with the **Program Planning/Scheduling Tool**, you will use various other tools such as the **Design Tradeoff Tool** for tradeoffs and the **Cockpit Product Tool** to produce documents which define and elaborate program plans, decisions, and schedules.

One, two, or possibly three documents critical to cockpit development could be created using the **Program Planning/Scheduling Tool**. The primary document prepared under the <u>Program Plan</u> is commonly known as the <u>Human Engineering Program Plan</u> recommended by MIL-H-46855. This document elaborates how the analysis, design, and evaluation activities performed by your personnel integrate into the design of the entire weapon system. The CDS supports this planning function, which allows you to select tradeoff analysis requirements from a list of activities, and helps you report the critical path for your project. This type of information enables you to schedule your team for parallel, interdependent activities.

- Develop Dynamic Simulation Plan

- Complete Dynamic Simulation Plan

The second document will only be developed if the program plan requires pilot-in-the-loop simulation. If so, then a <u>Dynamic Simulation Plan</u>, more commonly called out as the <u>Human Engineering Dynamic Simulation Plan</u> in MIL-H-46855, will be created. That document establishes the methodology, approach, data analysis, and scheduling of various types of piloted simulation. The CDS provides examples showing the type and number of simulations needed, based on crew/mission requirements and budget.

- Develop Flight Test Plan

- Complete Flight Test Plan

The third document that may be needed is the Flight Test Plan, more commonly called out as the <u>Human Engineering Test Plan</u> in MIL-H-46855. Again, if the plan calls for flight testing,

then CDS provides assistance in the development of that document. Usually, this document is not produced until the design is formalized somewhat later in the program. Another component of the overall CCCD Program, not currently resident as part of the CDS, is a support tool for cockpit evaluation during flight test, including guidance for preparing the cockpit flight test plan. That tool is called the **Performance Assessment and Workload Evaluation System (PAWES)**. It was purposely segregated from the CDS because, while cockpit development is largely an industry activity, the test role is shared, with the Government taking on a significant role in planning and performing flight test. Accordingly, stand-alone support for cockpit flight test is being developed, although integrating it into the CDS is feasible.

- Complete Program Plan

Near the time when the Up-Front Analysis activities are completed, you will *complete* the Program Plan. Your team, advised by the program plan information, now begins its respective technical work (which we categorize into "bins" of analysis, design, and evaluation process activities). As you can see from the Map, each of these functional areas begins in earnest at this point. Another facet of CDS is that it provides you, through either the **DTM** or the **Program Planning/Scheduling Tool**, a way to track the activities, or to read an engineer's status report electronically so that you can effectively manage your program. We do not imply, however, that you do this without direct contact with your team. The CDS merely makes that tedious job of tracking somewhat easier to manage. Since there are always tight time constraints, effective oversight of your progress relative to plan is needed.

CREW SYSTEM ANALYSIS

The following detailed map (Figure A-6) of Crew System Analysis will help guide you through this section of the document.

Upon receiving the information from both the Design Requirements Document and the Program Plan, with the specifics of how and when each analysis activity takes place, and the earlier Up-Front Mission Analysis, which provides a starting point, your team is ready to start two critical activities:

- Perform Mission Profile Analysis

- Complete Mission Profile Analysis Report

First, you would access the information from the earlier mission analysis information to provide the basic elements of the creation of a Mission Profile. Armed with this information members of the design team (particularly with operational experience of the design mission) would "brainstorm" a set of appropriate mission events for placement in the mission through a technique known as Concept Mapping. This technique has shown the unique ability to correlate the thoughts of operational experts toward consistent expressions of subject matter. The results of this effort can be obtained through the usage of the **Concept Mapping Tool**. Once the correlated mission events are obtained they can be placed into the **MDTOOL** as a means to implement a top-level mission profile for analysis. You can manipulate the variables to conform to the actual timing, environmental, and threat characteristics of the intended mission set. This activity concludes with a time-tagged, graphic portrayal of all mission events which are assumed to be critical to cockpit-related events. This information (on paper and in electronic media) can be used for IPD personnel for planning the subsequent piloted simulations for a "higher level" of verification and an early evaluation of realism and adequacy.

- Perform Life Support Analysis

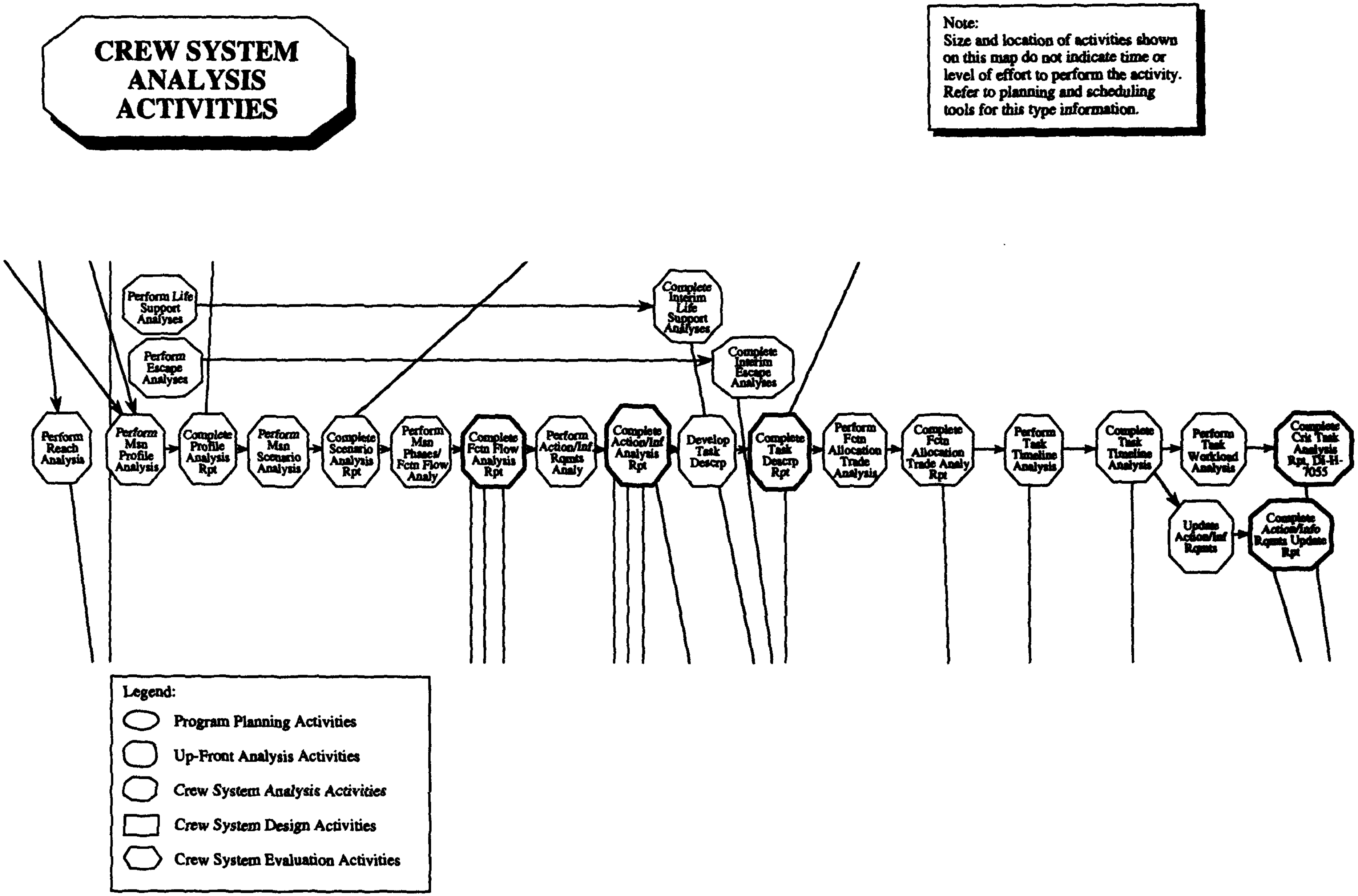


Figure A-6. Process Map - Crew System Analysis Activities

• Perform Escape Analysis

During the project, an analytical look at the intricacies of the Life Support System will be made to reveal the important integration factors determining outcome of cockpit design. We only acknowledge a great need for this analysis and do not delve into any further details here. Escape System and Life Support technologies are currently being advanced in separate advanced development projects within the DoD. The elements of crew protection (e.g., life support equipment, escape systems, environmental control) are critical to all cockpit development projects, especially for combat systems that employ ejection seats or escape capsules, and so the CCCD Process provides for their consideration during Crew System Analysis.

• Perform Reach Analysis

During the initial look into the cockpit layout and integration, it is vitally important that a detailed analysis of crew reach requirements is performed, to assure full access to controls and displays for the anticipated size range of the aircrew population. This is performed using a reach analysis computer model called **COMBIMAN**, which is supported by CDS and is already in use in the aircraft industry as a stand-alone cockpit accommodation tool. A clear determination of these requirements can be accessed versus the notional cockpit layout, and changes can be implemented interactively to understand their effects. Results from this analysis are used for cockpit *re-design* and serve as critical inputs for mock-up analysis activities. As a further verification of reach and clearances (usable also for the Escape Analysis), you also have on-line access to the Cockpit Accommodation Database, which can quickly check on reach and vision clearances, based on physical measurements of subjects seated in specific, existing military aircraft cockpits.

• Perform Mission Scenario Analysis

• Complete Mission Scenario Analysis Report

You then prepare mission scenarios for each of the mission profiles created. This activity requires you to provide a detailed script about mission activities for each crew member and to include system and environmental interaction. Specific mission scenarios will be elaborated in detail for all the mission segments that require analysis. Several databases will be at your disposal to help formulate the proper scripts within the **MDTOOL**. These scripts include normal, unexpected, and emergency conditions that put the crew system through as many (analytically stimulating) situations as possible. These same conditions will be used during Crew System Evaluation, and the scripts can be sent to the evaluation team via **MDTOOL**'s electronic output files or in a paper format.

• Perform Functional Flow Analysis

• Complete Functional Flow Analysis Report

Now that you have defined the mission purpose, profiles, and top-level activities that must take place, it is time to begin breaking down all facets of the mission using Functional Flow Analysis, which simply breaks down tasks to their lowest level. This is easily accomplished by using a graphical block diagram approach from within the **Functional Flow Tool**. This allows you to functionally break out the mission into its major segments (block I), all functional activities within each segment (block II), and each distinct task within each function (block III). Note that block III tasks can be delineated to as many levels as required. This breakout, along with a written description at each level, will prepare you for the next activity of Action/Information Requirements Analysis described below. The lowest level tasks will become the basis for the database of tasks that will be used within the **Timeline Management Tool** throughout all following analysis activities. When this activity has been completed, you will be able to discern *new* crew system

requirements and *update* both the Cockpit System Specification (through the **Cockpit Product Tool**) and the Cockpit Traceability Report (through the **DTM** and the **Cockpit Product Tool**), both of which provide the basis for a program review.

- Perform Action Information Requirements Analysis

- Complete Action Information Requirements Analysis Report

The development and analysis of Action/Information Requirements is the most critical activity for the development of control and display interfaces. These Action/Information Requirements are "cornerstone" elements from which you design the controls and displays. Our **Information and Control Requirements Analysis Tool** helps you to access databases that contain requirements for the type and class of aircraft in your development or modification project. The database (from within the **Timeline Management Tool)** started during Functional Flow Analysis continues to store information that will be added to here. You provide Action/Information Requirements for each (sequential and parallel) mission task, to associate and depict specific requirements with each phase of the design mission. You can look at the results from several perspectives (i.e., by crew member, by sub-system, or by individual requirement) to gain an understanding of how the requirements become distributed to crew members and subsystems. Guidance on this topic is also derived from the System Operational Requirements Document and the Cockpit Design Philosophy that will have already been established. This information will help you to develop the cockpit controls and displays and also to write an *enhanced* Cockpit System Specification with a technical justification of the design rationale documented in an *updated* Cockpit Traceability Report.

- Develop Task Descriptions

- Complete Task Descriptions Report

Armed with a *deeper* understanding of the Action/Information Requirements for each task throughout the mission, you can now further characterize the aircrew tasks with information from the same database used in each of the last two analysis activities. You lay out the sub-activities within each task, and then estimate the gross timing parameters. This activity allows you to reassess each of the lowest-level tasks in light of fully defined Action/Information Requirements. You also enter written descriptions that go along with the abbreviated tasks into a CDS Database within the **Timeline Management Tool**. This information will be used to further the design and evaluation of controls and displays and establishes the basis for future analysis.

- Perform Function Allocation Trade Analysis

- Complete Function Allocation Trade Analysis Report

The team has now developed the aircrew tasking in enough detail to make decisions regarding the implementation of the required system functions between crew members and subsystems, using Function Allocation Trade Analysis supported by the **Design Tradeoff Tool**. A CDS database allows you to use its stored information to create trades or to *reassess* trades using the results from this analysis. The CDS also is used to retrieve trade study information from similar aircraft, and you can further review the initial allocation using one of several variants of the Fitt's List (a list of attributes associated with strengths of man versus machine). This analysis concludes with a recommended crew member/subsystem allocation of work, with an *updated* database, and more importantly with a *new* description of the key requirements for the various air vehicle subsystem designers so that they can better factor the *analyzed* crew system requirements into their designs. Some *updated* requirements may dictate that *new algorithms* be created to support a mission or aircrew activity, which earlier may have been performed by crew members or

by dedicated subsystems (with or without monitoring or action by the pilot/crew). In either case, the design team needs this information to assess controls and displays. The *revised* database (from within the **Timeline Management Tool)** also supports Task Timeline Analysis, which follows.

- Perform Task Timeline Analysis

- Complete Task Timeline Analysis Report

Task Timeline Analysis is performed with support from the CDS's **Timeline Management Tool**. The **Timeline Management Tool** enables the team to assess the *new* baseline cockpit design (which will have been passed to you through the **Cockpit Product Tool**), to ensure that the new design meets the *updated* requirements at the pilot/crew task level. Here, you define specific requirements such as discrete motion, vision, speech, etc. Also, you will *update*, as needed, the physical aspects for each task such as reach distances (which you now have via the cockpit mockup evaluation, and supplemented by the **COMBIMAN** analysis of the cockpit geometry), types of reach, visual attributes, forces, releases, rotation angles, etc. You need to determine accurate and appropriate time values for each crew member task, based upon known subsystem designs, similar subsystem designs, or Methods-Time Measurement (MTM) estimates (contained within the **Timeline Management Tool**). You are then in a position to identify the total system delay times and sequential mission timing, derived and analyzed from within the **Timeline Management Tool**, to characterize the individual crew actions. This data will be used to formulate piloted simulator testing scenarios, to evaluate the cockpit design attributes in light of requirements, and to *update* the Action/Information Requirements Analysis and accomplish the Task Workload Analysis.

- Perform Update of Action/Information Requirements Analysis

- Complete Update of Action/Information Requirements Analysis Report

With the newly developed CDS Timeline Database (from within the **Timeline Management Tool**), which includes detailed timing aspects necessary to meet the *revised* mission and cockpit requirements, you perform a complete *update* of the Action/Information Requirements to discover if any new requirements exist, or if any old requirements can be efficiently combined (through display/control interfaces). The results should indicate that the cockpit design (concurrent development via the Crew System Design and Crew System Evaluation activities) continues to satisfy the established crew requirements. If not, then the design will need to be *changed* and the rationale for change will be recorded in the **DTM**. You provide the results, and your recommendation for change, to the design team. They will trade your new requirement against all related subsystem designs and reach a formal cockpit *design compromise* decision through the use of a **Design Tradeoff Tool** discussed in a later section.

- Perform Task Workload Analysis

- Complete Task Workload Analysis Report

While updating the Action/Information Requirements, the team needs to perform a detailed Task Workload Analysis. Using stored information from the **Timeline Management Tool**, you will annotate each task with the estimated discrete task workload, continuous load, and mode attributes. Then, you assign each task an appropriate workload attribute (mission segment dependent), and run a time-required-versus-time-available digital workload model. The CDS's **Workload Analysis Tool** will assist in performing this activity. Data flows from **Timeline Management Tool** directly into the **Workload Tool** to allow you to enter the proper variables from within the model. Example **CDS Databases** will assist you in performing this analysis. The results of this activity will be passed to your design team who will look for trends by crew

member. Later, you will compare these results to simulator values, to *verify* the adequacy of your design and your analytic predictions (if necessary).

GENERAL

The results from these CDS Analysis Tools will have a significant impact upon both the Crew System Design and the Crew System Evaluation activities within CCCD Process. Our intent is to provide both the methodology and the tools with which you derive and verify requirements. When done up front and quickly, your analysis can have a profound effect on requirements and cockpit design. Early identification and analysis of the aircrew's interactions with the cockpit, as they both evolve, becomes a tangible basis on which the various Integrated Product Teams can interact with your cockpit team, and assure that a crew-centered design approach will satisfy the cockpit user needs.

CREW SYSTEM DESIGN

Typically, you will prepare a functional, although notional, cockpit design. This is normally followed by a more detailed reflection of your preliminary design during the first month of the program. However, the real inception of detailed design must come from the results of analytical activities described earlier. This section will guide your team through the use of those results and how to further the design into specification-ready material. The following detailed map (Figure A-7) of Crew System Design will show you how the activities in this section of the document take place.

- Assess Results of Functional Flow Analysis

- Assess Results of Action/Information Requirements Analysis

- Update Cockpit System Specification

- Update Cockpit Traceability Report

While the origins of crew system design begin with Up-Front Analysis and a notional cockpit baseline, iterative design begins with the results from Functional Flow Analysis using the **Timeline Management Tool**, the product of which is housed in **Cockpit Product Tool** for review. A critical review will help to structure the makeup of the cockpit design by allowing the design team to understand the flow of lower-level crew tasks. With this understanding, the team can begin to design a cockpit layout (using the **Crew Station Geometry Tool**) and recommend all the cockpit information and control requirements using the **Information and Control Requirements Analysis Tool**, both of which are necessary for interface design and vital to Action/Information Requirements Analysis. With the results, the design team *adjusts* the **COMBIMAN** model and the cockpit mockup, which is soon slated for evaluation. Using the **Cockpit Product Tool**, you produce an *updated* <u>Cockpit System Specification</u> and will be ready for a program review. Your efforts to develop this new Cockpit System Specification will need to be documented. You will use **DTM** to *refine* the cockpit traceability record of the design to date.

- Prototype Controls and Displays

The results of the Action/Information Requirements Analysis provide the next opportunity for design change. Information retrieved from the **Cockpit Product Tool** and **Design Traceability Manager**'s intermediate traceability files will shape how the team devises various cockpit display formats before they begin to look at specific interface controls or displays. First,

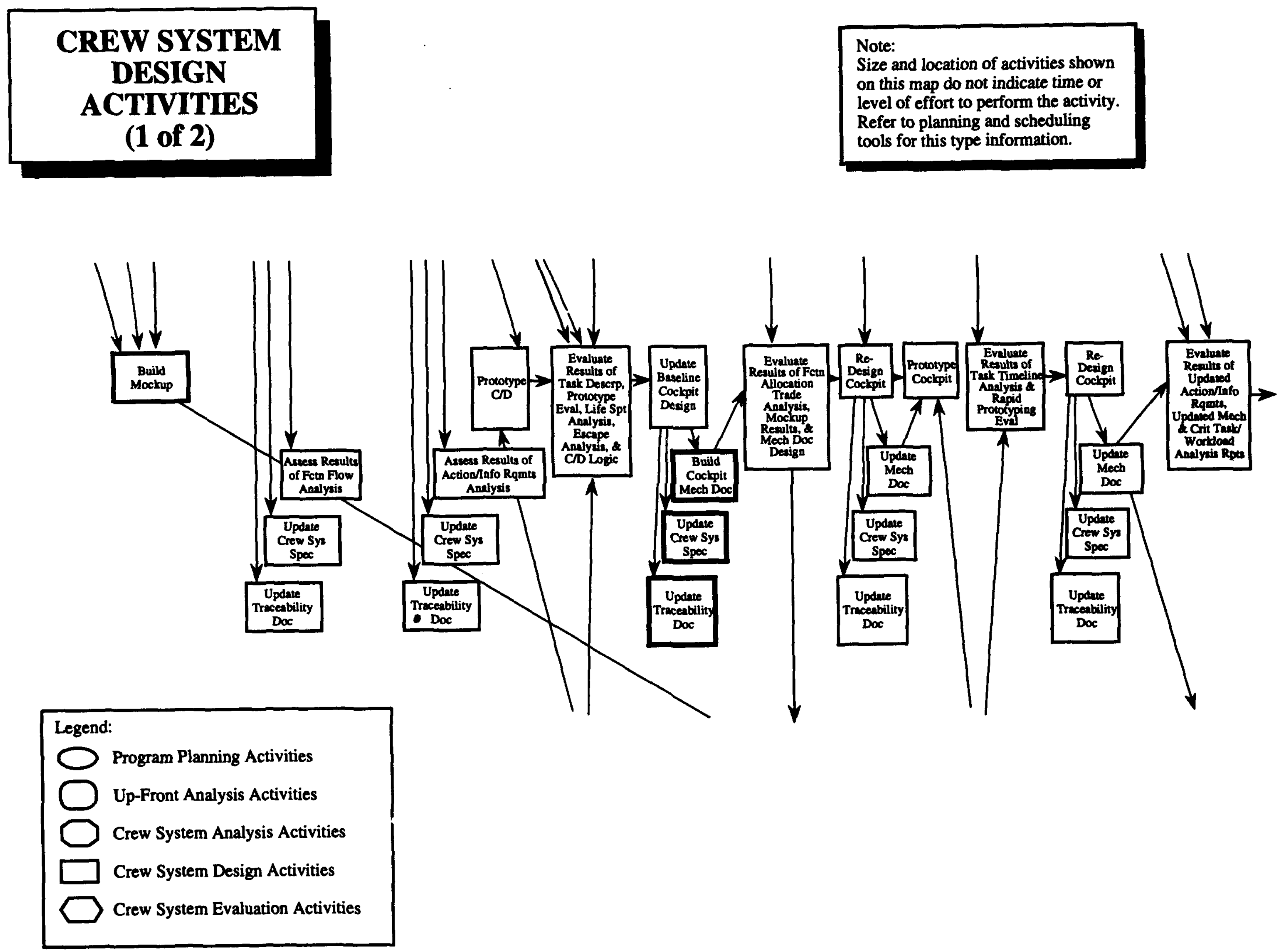


Figure A-7. Process Map - Crew System Design Activities (1 of 2)

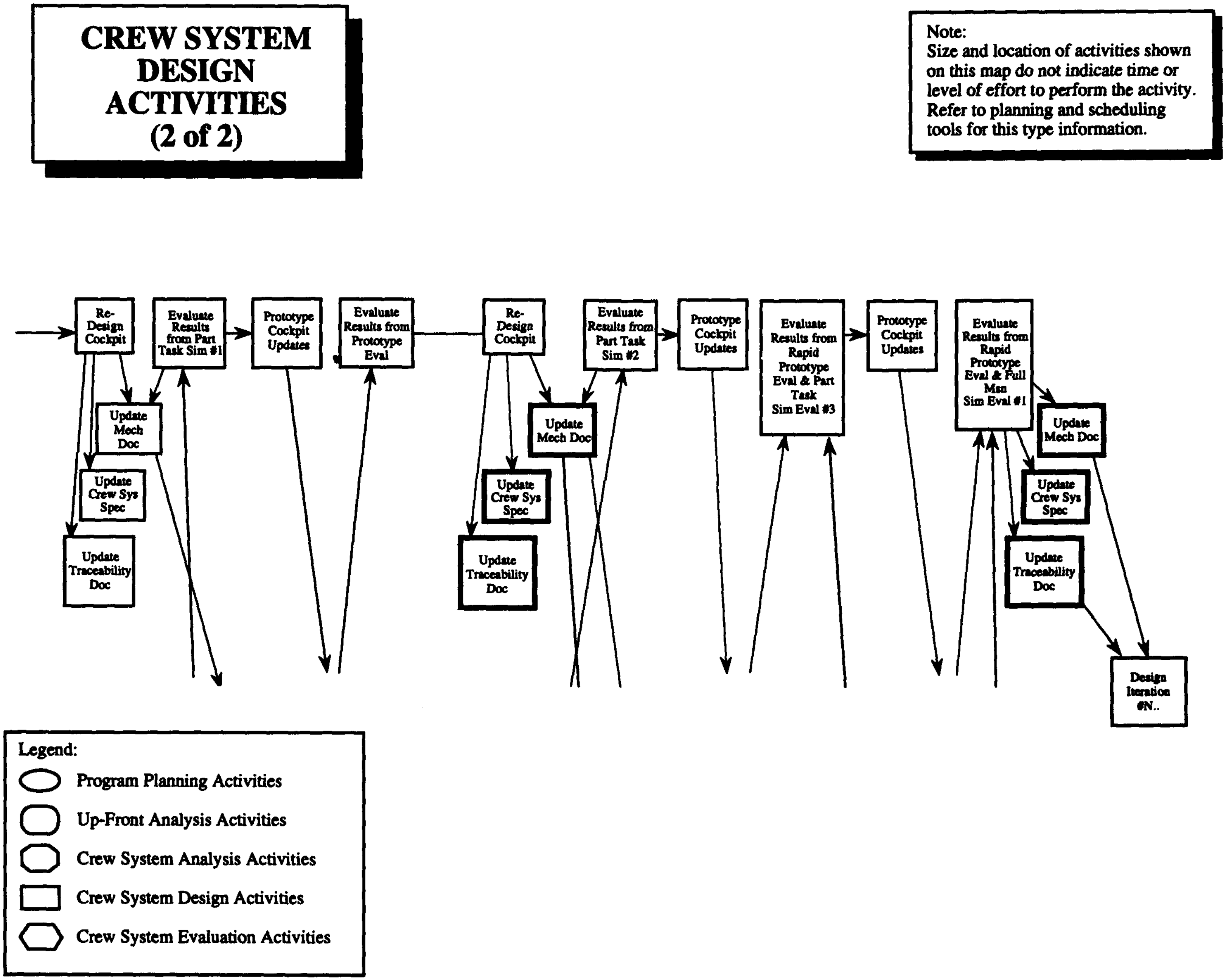


Figure A-7. Process Map - Crew System Design Activities (2 of 2)

you inspect requirements by functional categories: i.e., navigation, weapon fire control, target acquisition, etc. With those functional requirements, you are in position to envision displays and controls that meet the requirements. In particular, you review the products from the *updated* Action/Information Requirements Analysis, checking analytical results to see how they vary from original estimates. The team will cross-check its *evolving* designs against mission requirements (airspeed, missile launch envelope, map symbology, etc.) at representative times and places. Lastly, you review what information each crew member uses at various times in the mission. For instance, what information does the pilot need to operate the aircraft during low-level penetration? Do both crew members review threat assessment variables prior to launching missiles beyond visual range?

Your team will begin building several iterations of a design for each area of interest. The **Control and Display Development Tool** portrays each interface in varying style, layout, and color (if required). The CDS provides references that can help structure and standardize the design process through rules about font size, color, interface methods, symbols, etc. Using this basic design approach, your team will create a small number of candidate designs with the **Control and Display Development Tool**, choosing one or two for rapid prototyping evaluation.

- Perform/Complete Rapid Prototyping Evaluation

While technically an evaluation activity, Rapid Prototyping Evaluation is also often thought of as a design activity, as the two uses of this method overlap. This evaluation further *refines* the requirements, which will be documented, and spawns *new* designs. This is the key to interactive cockpit design: iterative design tradeoff cycles.

- Evaluate Results of Task Description Analysis, Rapid Prototyping Evaluation, Life Support Analysis, Escape Analysis and Control/Display Logic

In this CCCD Process activity, you contrast the results of the Rapid Prototyping Evaluation against the Task Description Analysis activity. This will provide tradeoff attributes for the **Design Tradeoff Tool,** which the team will use to justify how the *updated* design attributes should satisfy the crew and mission requirements. In addition, design information (from the tradeoffs), provides critical inputs to a Function Allocation Trades Study.

- Update Baseline Cockpit Design

These efforts will likely lead to redesigning the cockpit. This particular iteration yields in-depth design features, such as interface design descriptions, which become part of the <u>Cockpit Mechanization Document</u>, a "living" design guide for the team. With each redesign, one's understanding of the weapon system and its interface expands. One of the tools that will assist you in the development of the interface design is the **Mechanization Logic Tree Tool**. This tool helps you to structure the design by showing the logical interfaces among applicable subsystems. The logic diagrams will save time and increase your ability to influence the other subsystem designs by determining which interfaces need to become directly connected with the crew system and what supporting elements, such as algorithms, need to be specified.

- Build Cockpit Mechanization Document

- Update Cockpit System Specification

- Update Cockpit Traceability Report

Again, as with almost any design activity, the results of this effort lead to a <u>Cockpit Mechanization Document</u> and an updated <u>Cockpit System Specification</u>. Generally, only style and

depth, not content, differentiate the Cockpit Mechanization Document from the Cockpit System Specification. Both are a formal part of the CCCD Process and are supported by the CDS. The CDS stores the *new* Cockpit Mechanization Document and Cockpit System Specification and stores the design team *updates* in the Cockpit Traceability Report.

- Evaluate Results of Function Allocation Trade Analysis, Mockup Evaluation Results, and the Cockpit Mechanization Document to Update the Cockpit Design

Once you have reviewed the results of the Function Allocation Trade Study and the Mockup Evaluation Report, you would use the **Design Tradeoff Tool** to ensure that the functional allocation between individual crew member and system meets the *updated* requirements. This may cause you to *rethink* some of the functional design characteristics. Typically, *changing* the crew member of a system or sub-system only affects the control interface. Likewise, whenever an informational aspect *changes*, so will the crew interface, even if it affects nothing more than an input from a pilot's situational awareness perspective.

- Redesign Cockpit

- Update Cockpit Mechanization Document

- Update Cockpit System Specification

- Update Cockpit Traceability Report

Any change requires a potential cockpit redesign, including an *update* of the Cockpit Mechanization Document, Cockpit System Specification, and Cockpit Traceability Report. This *new mechanization feeds Rapid Prototyping Evaluation and forms the basis for Task Timeline* Analysis.

- Evaluate Results of Task Timeline Analysis and Rapid Prototyping Evaluation

- Redesign Cockpit

- Update Cockpit Mechanization Document

- Update Cockpit System Specification

- Update Cockpit Traceability Report

Next, use the **Design Tradeoff Tool** to compare and contrast results from Task Timeline Analysis and Rapid Prototyping Evaluations to enhance the cockpit design. The *changes* will require you to redesign the cockpit, document the redesign through an *updated* Cockpit Mechanization Document, and Cockpit Traceability Report. You are now positioned to present and explain the resulting Cockpit Mechanization Document to the project's simulation and evaluation personnel to prepare them for further cockpit evaluation issues.

- Evaluate Results of Task/Workload Analysis, updated Action/Information Requirements, and the updated Cockpit Design

Next, you apply the results of the Task/Workload Analysis and Action/Information Requirements Analysis (as well as current design characteristics) to critique and revise the design. You also will *update* the Cockpit Mechanization Document. This begins yet another iteration of design rapid prototyping and evaluation. [illegible]hen evaluate *new* against old workload predictions to see if the pilot and other crew member t[illegible] come more manageable.

- Redesign Cockpit
- Update Cockpit Mechanization Document
- Update Cockpit System Specification
- Update Cockpit Traceability Report

Cockpit redesign follows, as do *changes* to the Cockpit Mechanization Document, Cockpit System Specification, and Cockpit Traceability Report in time for a program review. Again, you will coordinate the Cockpit Mechanization Document with the simulation and evaluation personnel to ensure that the design will be properly evaluated.

- Evaluate Results from Part-Task Simulation Evaluation #1

The results of the first Part-Task Simulation will be prepared in two ways, as a Part-Task Simulation Evaluation Report, and as an intermediate **DTM** Traceability File that explains the reasons behind the test team's conclusions and recommendations. You then reassess the crew system design in light of those conclusions and recommendations as well as inputs from the overall design team. This is the first time your design is judged against real-time crew member expectations. The majority of the cockpit design will begin to *change* in terms of detailed software interfaces. This can be both in visual formats and symbology to the crew members and subsystem detailed interfaces. Potentially these changes can even accommodate *evolving* requirements. There will be many duplications of informational requirements which you will be better able to manage, with support from the CDS, using the results of piloted simulation. This will also be an excellent opportunity to apply the **Design Tradeoff Tool.**

- Perform/Complete Rapid Prototyping Evaluation
- Evaluate Results From Rapid Prototyping Evaluation
- Redesign Cockpit
- Update Cockpit Mechanization Document
- Update Cockpit System Specification
- Update Cockpit Traceability Report

The previous activities employ a series of rapid prototyping design iterations. At each step, you continue to evaluate while incorporating *changes* to the cockpit design. At each redesign, you again need to *revise* the Cockpit Mechanization Document, Cockpit System Specification, and Cockpit Traceability Report. At this point, you review the *updated* Cockpit Mechanization Document, and resolve issues from the Part-Task Simulation Evaluation Report and the Full-Mission Simulation Evaluation Report, with the simulation and evaluation personnel, again, to ensure that the design is progressing well.

- Evaluate Results from Part-Task Simulation Evaluation #2
- Perform/Complete Rapid Prototyping Evaluation
- Evaluate Results From Rapid Prototyping Evaluation and Part-Task Simulation Evaluation #3

- Perform/Complete Rapid Prototyping Evaluation

- Evaluate Results From Full-Mission Simulation Evaluation #1

At this point, you will probably know the results from the second Part-Task Simulation Evaluation Report, in which case you need to reassess its conclusions and recommendations, in light of how you designed the cockpit. This may lead to another rapid prototyping cycle and a *revised* design approach. You then determine what *changes* are truly necessary for the cockpit design. You may also have the results from the third Part-Task Simulation Report to *add* to the Rapid Prototyping Evaluation results. At this point, the rapid prototype evaluation team should *re-evaluate* the cockpit prototype controls and displays. The results of this evaluation should coincide with the results of the first Full Mission Simulation Evaluation Report. This iterative process of evaluation and redesign naturally leads to a more robust *redesign*, with the obvious human factors problems resolved and documented along the way. You should truly have your first full look at all of the integration factors which are necessary for the cockpit. Until this point, the best your design could hope for is that each of the individual subsystem designs had been through enough Rapid Prototyping or Part-Task Simulation Evaluation cycles to "come together."

- Redesign Cockpit

- Update Cockpit Mechanization Document

- Update Cockpit System Specification

- Update Cockpit Traceability Report

Once the cockpit redesign is approved, you will need to make the appropriate *changes* to the Cockpit Mechanization Document, Cockpit System Specification, and Cockpit Traceability Report before the scheduled program review. At that point, you present and explain the critical Cockpit Mechanization Document issues in advance of the *next* Part-Task Simulation Evaluation (if any) and Full Mission Simulation (if any), to ensure that the designs will be evaluated properly in each case.

GENERAL

The above iteration and interaction cycle can be performed as many times as necessary (given the available time and resources) to accomplish design goals. Once fully developed and proven, the CDS will enable more design iterations and design quality checks. We chose a representative number of activities to show that sometimes the same activities take on a slightly different "twist," due to the state of development and the type of available information and results from analyses and tests. Note that a great deal of activity is implied for both the analysis and the evaluation activities.

CREW SYSTEM EVALUATION

Given the Design Requirements Document direction for the cockpit and a Program Plan with the specifics about each evaluation activity to take place, and also given the CCCD analysis information about the specific evaluation requirements, you will be ready to plan and perform an orderly progression of Crew System Evaluations. As in current practice, evaluation is a continuing activity as the cockpit design evolves. With the CCCD Process, the evaluations progress in an orderly manner, from early studies that would be totally supported by the CDS, to separate physical and lighting mockups, to larger-scale incorporation into avionics hotbenches and flight

control fixtures, and eventually within weapon system simulators (including ground-based domed simulators and in-flight simulators). This document focuses on the use of real-time piloted simulation for verifying the crew system operability, although all types of evaluation will be performed.

The following detailed map (Figure A-8) of Crew System Evaluation will help guide you through this section of the document.

- Develop Dynamic Simulation Plan

- Complete Dynamic Simulation Plan

If the Program Plan requires pilot-in-the-loop simulation testing, then you would prepare a Dynamic Simulation Plan using the **Program Planning/Scheduling Tool** and **Cockpit Product Tool**. The Dynamic Simulation Plan will document the methodology, approach, data analysis, and scheduling of cockpit simulators. Simulators could include part-task and full-mission simulation devices. As previously stated, the CDS provides some assistance in planning the number and nature of simulation tests, using your crew/mission requirements and budget as constraints.

- Plan Part-Task Simulation Evaluations

- Plan Full-Mission Simulation Evaluations

Once you have completed the Dynamic Simulation Plan, you begin the actual preparation for specific Part-Task Simulator design evaluations. This will require that you have an agreed-upon baseline of the design to evaluate. Formal test planning can be developed through the **Simulation Test Planning Tool** where a database of ideas, methodology, tradeoff of requirements, and data analysis techniques can be accessed to promote viable evaluations. Similarly, you will plan for any Full-Mission Simulation evaluations that need to occur. Actual evaluation plans will be produced using the **Cockpit Product Tool** to conform to project-specific formats.

The CCCD Program has published a document which will be the basis for this tool development. This report can be retrieved from DTIC as HSD-TR-90-007, "Handbook For Conducting Pilot-In-The-Loop Simulation For Crew Station Evaluation," Accession number B141991.

- Plan Mockup Evaluation

- Plan Rapid Prototyping Evaluations

Other evaluations also need to be planned. These can vary in nature. For example, you will plan a cockpit mockup evaluation as soon as the team formalizes the cockpit's preliminary design, as a *further check* against your **COMBIMAN** analysis. You will plan the Rapid Prototyping Evaluations that were previously discussed under Crew System Design. You will also prepare the overall evaluation team to stay abreast of the *evolving* cockpit analysis results and the *evolving* design requirements. With support from the CDS, you will be in a position to help them to develop quick methods to extract evaluation data from each Rapid Prototyping Evaluation, especially data that is pertinent to the needs of the other air vehicle subsystems.

- Perform Part-Task Simulation Evaluations

- Perform Full-Mission Simulation Evaluations

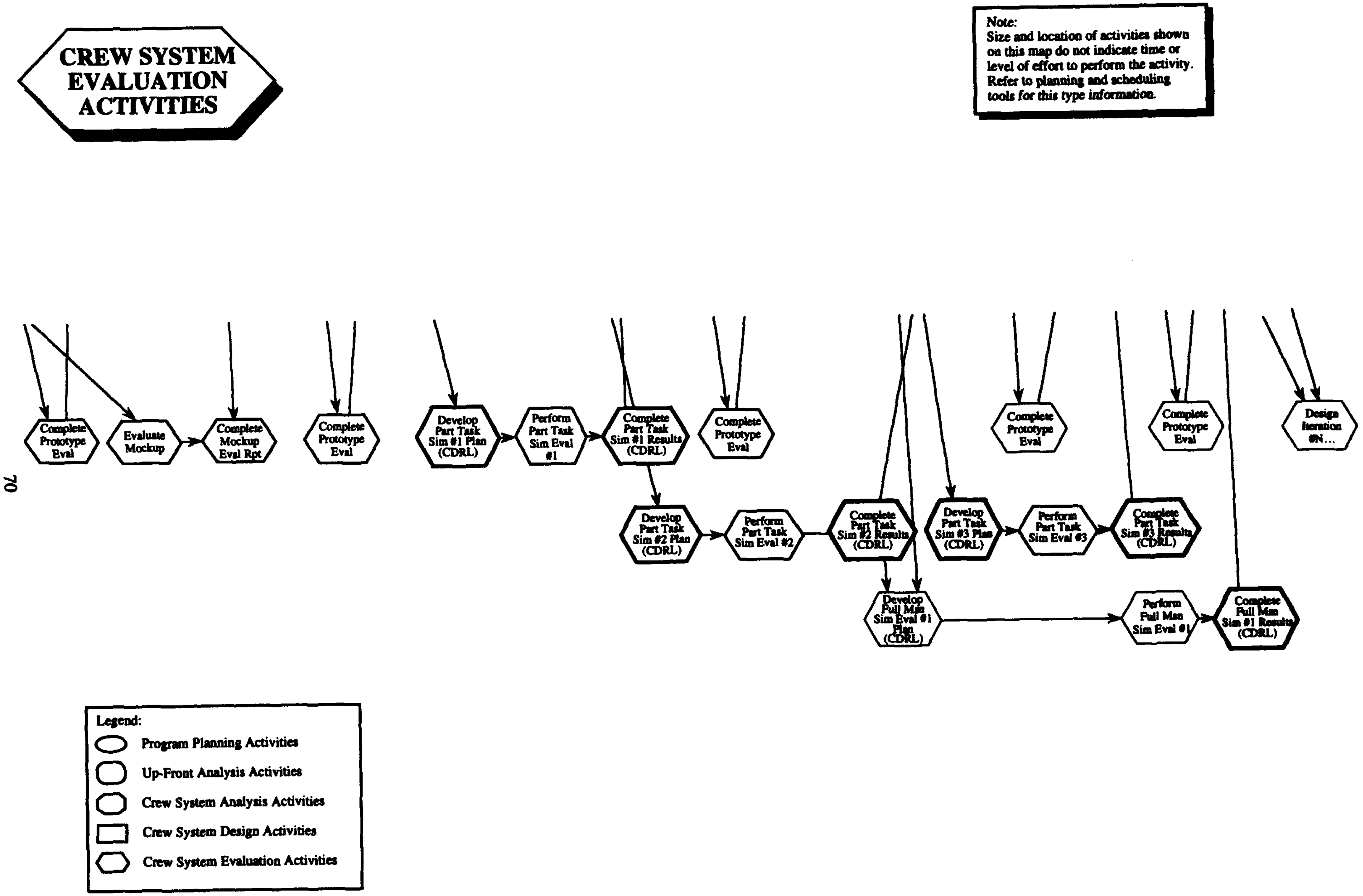


Figure A-8. Process Map - Crew System Evaluation Activities

Throughout the life of the program, a need to perform (potentially several) Part-Task and Full-Mission Simulation Evaluations will be emphasized to place your design under realistic conditions for overall system integration. With the use of Structured Test Plans and Procedures, accessible on the CDS via the **Simulation Test Planning Tool**, your team can produce meaningful results in time for re-use by other subsystem design teams. Typically, the simulation personnel follow the direction of the crew system Integrated Product Team in completing simulation evaluations. It is imperative that someone from the your design team be responsible for those activities so the data can be analyzed with crew-centered cockpit design as the driving force.

- Complete Part-Task Simulation Evaluation Results

- Complete Full-Mission Simulation Evaluation Results

All evaluation results, whether in the form of specific conclusions or general recommendations, will be inserted into the design evaluation tradeoff matrix for your program. Therefore, you are advised to use a mix of qualitative and quantitative methods to strengthen conclusions and recommendations. Further, you should strive to include timely indications and trend information to show how the crew performs the mission, rather than including "data dumps." Cost and schedule will severely constrain your ability to exhaustively examine all of the simulator test results. The CDS provides support through the **Simulation Test Planning Tool**, which helps you to create a balanced series of appropriate evaluations that conform to program needs.

- Develop Flight Test Plan

- Complete Flight Test Plan

If the Program Plan mandates flight testing, you will prepare a Flight Test Plan using the CDS **Program Planning Tool** (or **PAWES**) and the CDS **Cockpit Product Tool**. This plan documents the methodology, approach, data analysis, and scheduling of various types of flight test activity to coincide with the rest of the flight test program.

- Plan Developmental Test and Evaluation Flight Tests

- Plan Operational Test and Evaluation Flight Tests

Flight test evaluation is handled differently than simulator evaluation. The goal of flight testing, both Developmental Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E), is to measure the ability of the system or subsystem item to meet the original requirements. DT&E addresses design requirements, whereas OT&E evaluates against operational requirements. While the two evaluation types, DT&E and OT&E, are substantially different in nature (and include increasing participation by the military customer in planning and performing these tests), they do abide by similar techniques of structured, "by-the-book" testing. Where possible, the variables are controlled and the test items are isolated in an attempt to validate the test article.

In the future, the CDS will support your ability to plan and execute flight test activities, based on crew and mission requirements, as well as budget. As was mentioned above, the CCCD Program Office is developing a cockpit flight test support tool (PAWES) for that purpose. PAWES has already achieved considerable acceptance from the flight test community and will be undergoing field trials at the Air Force Flight Test Center during FY94. Hopefully, a similar state of user acceptance and support for the CDS will develop within the industry crew system design community as the system matures and is proven through use in actual applications.

SECTION 4.0: CONCLUSION

The CCCD Process heavily relies upon user interaction and design iteration to improve the cockpit design product quality. Conversely, we believe that you will also heavily rely upon the CDS and its supporting toolset, to improve your cockpit design process. With your help, and with your constructive recommendations for improvement, we will be able to make a joint contribution to advancing the overall practice of crew system design.

ACRONYMS

CAD	Computer-Aided Design
CADAM	Computer-Aided Design and Manufacturing
CALS	Computer-Aided Acquisition and Logistics System
CAM	Computer-Aided Manufacturing
CAT	Cockpit Automation Technology
CATIA	Trade name for the Dassault CAD/CAM package
CCCD	Crew-Centered Cockpit Design
CD	Compact Disc
CDDT	Control and Display Development Tool
CDRL	Contract Data Requirements List
CDS	Cockpit Design System
CMT	Concept Mapping Tool
COMBIMAN	Computerized Biomechanical Man Model
CPT	Cockpit Product Tool
CSDP	Crew-Centered System Design Process
CSGT	Crew Station Geometry Tool
CSS	Cockpit System Specification
DBMS	Database Management Software
DOD	Department of Defense
DT&E	Developmental Test and Evaluation
DTIC	Defense Technical Information Center
DRD	Design Requirements Document
DTM	Design Traceability Manager
DTT	Design Trade-off Tool
ECM	Electronic Counter-Measures
ECP	Engineering Change Proposal
EDSIM	Engineering Design Simulator
FATAT	Function Allocation Trade Analysis Tool
FFAT	Function Flow Analysis Tool
GUI	Graphical User Interface
HFE	Human Factors Engineering
ICRAT	Information and Control Requirements Analysis Tool
ILS	Integrated Logistics Support
IMICS	Integrated Master Information Control System

IPD	Integrated Product Development
IPT	Integrated Product Team
IWSM	Integrated Weapon System Management
JPATS	Joint Primary Aircraft Training System
LASC	Lockheed Aeronautical Systems Company
MCAD	Mechanical Computer-Aided Design
MDTOOL	Mission Decomposition Tool
MLTT	Mechanization Logic Tree Tool
MOEs	Measures of Effectiveness
MTM	Methods-Time Measurement
NTIS	National Technical Information Service
OT&E	Operational Test and Evaluation
PA	Public Affairs
PAWES	Performance Assessment and Workload Evaluation System
PC	Personal Computer
PIDS	Prime Item Development Specification
PIL	Pilot-in-the-Loop
PPST	Program Planning and Scheduling Tool
PVI	Pilot-Vehicle Interface
QFD	Quality Function Deployment
RFP	Request for Proposal
SAE	Society of Automotive Engineering
SEMS	System Engineering Master Schedule
SGI	Silicon Graphics Incorporated
SMEs	Subject Matter Experts
SON	Statement of Need
SORD	System Operational Requirements Document
SOW	Statement of Work
SPO	System Program Office
STPT	Simulation Test Planning Tool
SWAS	Sequitur's Workload Analysis System
SWAT	Subjective Workload Assessment Technique
TAKE	Tool for Automated Knowledge Engineering
TAR	Threat Assessment Report
TMT	Timeline Management Tool
USAF	United States Air Force

VAPS	Virtual Avionics Prototyping System
WAT	Workload Analysis Tool
WBS	Work Breakdown Structure
WSDP	Weapon System Development Program
WSS	Weapon System Specification

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